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Validity and reliability of dynamic virtual interactive design methodology

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VALIDITY AND RELIABILITY OF DYNAMIC VIRTUAL INTERACTIVE DESIGN METHODOLOGY

By

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This study focuses on testing the validity and reliability of dynamic Virtual Interactive Design methodology with dynamic ergonomics analysis. This methodology has been validated with static ergonomics analysis tools. Although most results prove the validity and reliability, those processes are not sufficient since risks can not be fully examined without examining dynamic aspects. So validity and reliability of the dynamic Virtual Interactive Design environment need more investigations.

In this study, a dynamic ergonomics analysis tool is integrated, and dynamic analysis results are achieved. Also, dynamic ergonomics risk results for motion captured directly from human subjects and static ergonomics risk results from virtual interactive design environment are calculated, which are used as standards. Comparisons between interested and standard motion series with respect to ergonomics risk results are applied for testing validity. And test-retest method is used for testing reliability.

Key words: virtual interactive design, dynamic ergonomics analysis, digital human modeling

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CHAPTER I

INTRODUCTION

This study will focus on testing the performance of Virtual Interactive Design (VID) methodology based on dynamic ergonomics analysis. In this part, basic knowledge and terms will be described, and where the study derives from and contributes to will be introduced.

1.1 Ergonomics and Related Technologies

1.1.1 Ergonomics and Ergonomics Aspects in Design Process

We live in a world that has been transformed by technology. HFE (Human Factors and Ergonomics) represents a new discipline that has developed out of that technology. HFE is a discipline that attempts to change that technology by introducing the influence of the human and humanistic concerns without losing its scientific credentials (Meister, 1999). Nowadays the science of ergonomics stands for the knowledge of the interaction between human and technique and environment (Miljomedicin, 2003), and mainly includes three aspects focusing on different features of human which are load ergonomics, cognitive ergonomics and organizational ergonomics. This study is mainly in the domain of load ergonomics, which considers physical activity and load and how they are related to the human anatomy, physiology and biomechanics, with a main application of improving the design of work and workplace (Johansson, 2004).

One key contribution of considering ergonomics in workplace design is to reduce the occurrence of Work-related Musculoskeletal Disorder (WMSD), such as low back pain, hand-arm vibration syndrome and carpal tunnel syndrome (CTS), account for a major component of the cost of work-related illness in the United States. Recent estimates of the costs associated with work-related musculoskeletal disorders range from $13 to $54 billion annually (NOISH, 2001). Regardless of the estimate used, the problem is large both in health and economic terms (Bureau of Labor Statistics, 1997). Many researches have been done on reducing WMSD by considering ergonomics features (O'Neill, 1994) (Colombini, D., 2000) (NOISH, 2001).

Furthermore, as Broberg (1997) presented, integration of human aspects into the technological planning processes in a company is a major strategy for the prevention of work-related injuries and illnesses among employees in manufacturing facilities, and over 90% of the system designers and engineers surveyed recognized that they needed to consider ergonomics earlier in the development processes than is now the case. Chaffin (2001) has pointed out the benefits of considering ergonomics aspects in early design process, shown in Figure 1.

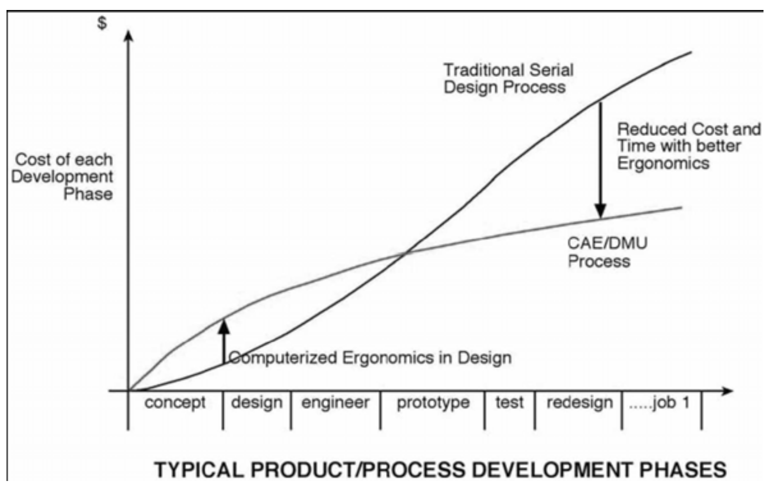

Figure 1

Typical development phases and hypothetical cost profiles when using a DMU

1.1.2 Computer-aided Ergonomics

With the development of computer technology and change of the demands, Ergonomics, as the science to fitting the work environment to human worker, has received greater assists from computer-related technologies since the last two decades. Computer-Aided Ergonomics Methods can be defined as the implementation of information technology in ergonomics and safety methods and the integration of those methods into design, production and decision making (Mattila, 1994). Kurila (2005) has pointed out that a wide variety of ergonomic topics are of relevance to the application of computer-aided design systems concerned with layout design, displays and controls, fields of vision, areas of movement, physical strength and working environment. And various computer systems have been developed that can be categorized as follows:

1. Computer-based checklists for design quality analysis such as the FMS Safety Checklist;
2. Computer-supported risk analysis like STARS – a program package for computer-aided safety and reliability analysis;
3. Knowledge-based expert systems in ergonomics and safety, like M-LIFTAN, ALIE, and GSA;
4. Ergonomic oriented information systems for workplace designers;
5. Computer models of man;
6. Systems for the measuring of 3-dimensional postures;
7. Computer-based tool for evaluation

Numerous studies have been put on the computer-aided ergonomics, and Feyen and Chaffin (2000) has given a round review of the progress of CAE researches, which can be basically summarized to follow 4 approaches: (1) use computer-aided techniques to evaluate the performance of human operators in a workplace design; (2) develop integrated tools that allow ergonomics information from several sources to be examined before an actual job is implemented -- a "proactive" rather than "reactive" approach; (3) One approach has been to develop three-dimensional CAD programs with built-in ergonomics assessment capabilities; (4) Another approach has been to develop complementary software that provides the evaluative aspects and interface while using commercially available CAD systems to provide the three-dimensional modeling requirements. Jarvinen and Lu (1999) have also summarized the applied computer software developed for ergonomics analyses.

1.1.3 Digital Human Modeling

The aim of ergonomics is to generate working conditions that advance safety, wellbeing, and performance (Kroemer, et al., 1994). One important implementation is to test the validation and usability of designed product, and the use of rapid prototype and virtual reality techniques has greatly influenced design procedures and methods (Arzi, 1997). Human modeling is not a new design tool, since for decades, wooden and plastic dimensionally accurate templates have been used in the design of automobiles and aircraft (Jarvinen and Lu, 1999). With the use of computer-aided technology and virtual reality technology, digital human model has come into reality -- for improvement of the physical aspects of a product or manufacturing work cell, many ergonomics analysis tools allow a designer or engineer to create an avatar (virtual human) with specific population attributes on their personal computers, which can then be inserted into their 3D graphic renderings of their proposed designs (Chaffin, 2005). Figure 2 shows a typical digital human figure model.

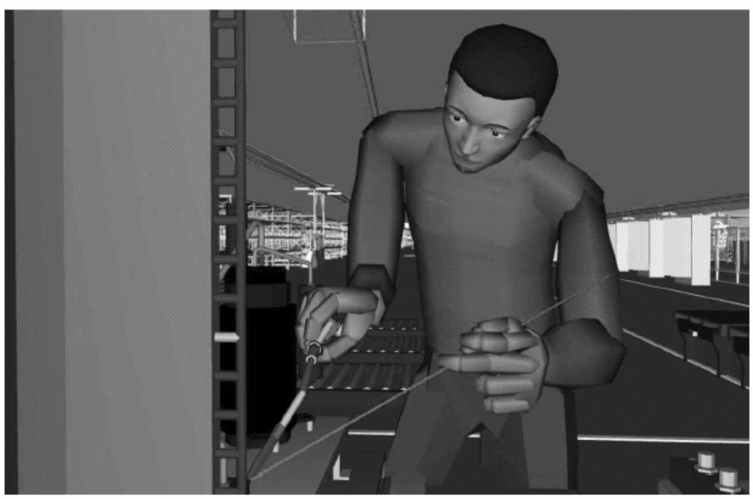

Figure 2

A typical digital human figure model for static analysis
(Courtesy of Ulrich Raschke, EDS-PLM).

As a technology, digital human modeling is a means to create, manipulate, and control human representations and human-machine system scenes on computers for interactive ergonomics and design problem solving. As a fundamental research area, digital human modeling refers to the development of mathematical models that can predict human behavior in response to minimal command input and allow realtime computer graphic visualization (Xudong and Chaffin, 2005). The DHM provides the ability to construct 2D or 3D human models from anthropometric data, which can be articulated between the body segments to simulate a wide variety of postures. These human models can then be used as substitutes for "the real human" in ergonomic evaluation of computer-based design for vehicle, work area, machine tool, assembly line, and etc. (Badler, 1997).

Currently, digital human modeling is more and more widely used in design process, because it allows easier and earlier identification of ergonomics problems, and lessens or sometimes even eliminates the need for physical mock-ups and real human subject testing (Badler et al., 1993; Morrissey, 1998; Zhang and Chaffin 2000), and it help the ergonomist to be more proactive in the design process and to be able to work closely with other design team members to achieve the ergonomic solutions to the design within the various financial, legal, engineering, and aesthetic constraints (Porter et al., 1999).

Recent improvements in computational speed and control methods allow the portrayal of 3D humans suitable for interactive and real-time applications. And over the past a few years, several commercial DHM software has been developed. It has been widely accepted that the DHM can assist us in designing better workplaces and products (Chaffin, 2003a; Porter et al., 1999; Gill et al., 1998). Chaffin (2001) has reported seven cases of actual use of DHM in enterprises, and summed up main utility of DHM nowadays including trying to: simulate people of extreme sizes for the purpose of providing designs that will accommodate a large variety of people; predict a population's reach and clearance capability; determine how much human strength and/or endurance was required to perform a manual exertion; allow both product and process designers to better understand the potential problems by simulation and associated graphics. Also, most commercial software and how they can be implemented have been summarized by literatures (Chaffin, 1999; Delleman, et al., 2004). While, Chaffin (2005) pointed out two most important problems of current DHM technologies:

1. One major limitation appears to be due to the lack of data sharing capabilities, thus requiring a designer to spend a great deal of extra time rendering a workspace with enough detail to perform an analysis.

2. Another problem revealed in the case studies is that the designers were not capable of predicting how a person of certain characteristics should be positioned in the virtual workplace, especially if dynamic motions are of concern.

1.1.4 Motion Simulation Model

In the research field of digital human modeling, investigation on motion simulation model is paid a lot attention. Chaffin (2001) pointed out that it is important to increase the ability of existing DHM to predict position, posture and motion of a person of certain characteristics. So human motion modeling has got much attention from researchers recently, and a structure called integrated dynamic human simulation model is created by combing human motion model with biomechanical models (Chaffin, 2005).

Motion Modeling Methods

At the very core of digital human modeling and simulation is a model – a biomechanical representation of a human body along with the computational algorithms that configure or drive the representation to produce postures or motions (Zhang, 2005). The biomechanical representation which is a kinematical human model, and human motion or posture prediction models which are those algorithms driving the avatar will be reviewed in this section.

Kinematical Human Model

Human skeletal model is a biomechanical linkage for representing segmental links and joints of human body. This serial linkage may represent the whole body, or a part such as an arm, a leg, etc. Since joints vary quite differently although the body, the complexity of various joints must be modeled well, such as the shoulder complex. Various models have been constructed, and two full-body models that will be used in this study, Jack and Santos, will be reviewed.

Jack (Badler, 1993) is a 125-DOF scalable model with a flexible torso model and a simplified shoulder joint model. In Jack software, articulated figures (of Peabody) can be got through inverse kinematics. The structure of the Peabody structural tree is defined by designating one site on the figure as the *root*. The root site roughly corresponds to the origin of the figure, and it provides a handle by which to specify the location of the figure. Then the dependent joints form a group to represent any poses of Peabody by identifying their angles.

Santos (Yang, et al, 2004) is developed by Virtual Basic Program in University of Iowa. It is a 101-DOF rigid body model, and the movements of each joint of the torso, shoulder and arm, hand, neck, leg and foot are analyzed and modeled. DH notation (Denavit, 1955) is used to systematically establish the coordinate system to each link of articulated chain for Santos, which defines four parameters to describe the linkage based on measurements between the axes of a robot manipulator.

Three aspects should be considered to construct a skeletal model (Zhang, 2005): Whether all the degrees of freedom (DOFs) are accounted for, whether the centers of rotation (CORs) or axes of rotation (AORs) are correctly identified, and whether the link segment dimensions are accurately represented. Based on many researches about the segment lengths and joint centers (Zhang et al., 2004; Chaffin et al., 1999b), and the limitation of current methods for COR derivation which need a too-large minimum number of markers affixed to each body segment, Zhang (2005) summarized that *it is exactly in some areas that the existing linkage representations need improvement.*

Posture and Motion Prediction Model

Researchers in the field of ergonomics have been continuously working on developing models to realistically predict how people normally move and interact with systems for several decades. From the very beginning of 2-D static and dynamic posture models, to 3-D sequential–static models, to 3-D dynamic models, four classes can be jointly defined by two dimensions: with or without musculature: static or dynamic (Zhang, 2005). In the concerning field of this study, only static (posture) and dynamic (motion) model without musculature will be considered.

Two approaches are commonly used for posture prediction: empirical-statistical modeling and inverse kinematics solution (Yang, et al, 2004). The first method is based on captured real human motions, and uses statistical method, such as regression, to calculate most probable posture. Models belong to this logic include Zhang and Chaffin (1996), Faraway (1999). The second method mostly uses static optimization and inverse kinematics to solve a discrete posture determination problem (Zhang, 2005).

Some optimization-based human-figure positioning algorithms for computer animation belong to this class. Although these sequential or quasi-static posture prediction models can animate human dynamic motions, there are two limitations: they are computationally highly intensive, and some key characteristics possessed by real human motions like smooth velocity and acceleration can not be simulated by these models.

In constructing dynamic models without musculature, the key challenge is kinematic redundancy in inverse kinematics, so-called Bernstein's problem (Bernstein, 1967). Data-based motion prediction methods, which rely on extensive collections of motion capture data, can statistically analyze human motion data to form predictive models (Faraway, 2003). This approach uses statistical or curve-fitting techniques to directly model measured body segment of joint angles (Zhang, 2005). Also, optimization-based methods have been widely studied and constructed nowadays, because of its ability to solve kinematic redundancy problem. Many models (Chen, 1991; Lo, 2002) based on optimization use systems of linear equations (inverse kinematics) to calculate human motions includes joint angles and velocities, by minimizing the result using muscle-stress-type or some other cost functions with high calculating load; while Zhang (1998) improved the optimization-based method by resolving the kinematic redundancy in the velocity domain.

Integrated Dynamic Human Simulation Model of HUMOSIM in Michigan is shown as Figure 3.

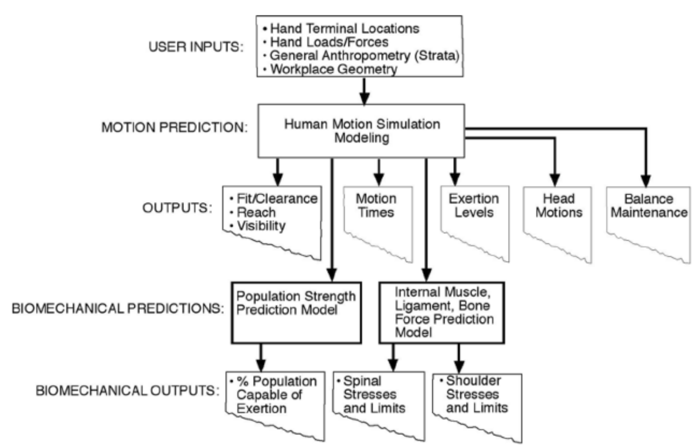

Figure 3

Structure of integrated dynamic human simulation model

Chaffin (2005a, 2005b) summarized all the motion modeling work been done in HUMOSIM lab in university of Michigan, includes functional regression method for reach modeling and motion engineering algorithm development, and pointed out the structure of integrated dynamic human simulation model, shown in Figure 3.

In this integrated model, existing biomechanical models were linked to the motion kinematics model, and the predicted motions can drive the biomechanical models to generate biomechanical outputs for ergonomics analysis. As mentioned above, this integrated model can "generate" human motions by itself, rather than driven kinematic linkage model by captured motion directly, like Virtual Build Methodology.

Recent research of HUMOSIM about motion prediction models mainly includes three aspects. Based on the experiment of collecting human seated reaching movement in 1997, both data-based (Faraway, 1997) and optimization-based (Zhang, 1997a; Zhang, 2000) human motion prediction models are promoted, and following work has been done on improving these two angle-based models. For the statistical regression model, initially input parameters include stature, age and gender, whose sensitivity has been examined (Chaffin, et al. 2000), and Faraway (1999b with Zhang, 2003) continuously added end-point constraint to avoid the limitation of angle-based model in forward kinematics.

Another effort of HUMOSIM is developing motion engineering algorithm, a memory-based human motion simulation. Motion engineering system consists of three components: a motion database, a motion search and comparison method, and a motion modification algorithm (Chaffin, 2005). Park et al. (2002, 2005) pointed a "symbolic coding" methods for motion search and comparison, and Park et al. (2004) promoted a "motion modification algorithm" for generating the final predicted human motions.

1.1.5 Motion Capture Systems (MOCAP)

In the research area of ergonomics and digital human modeling, human motion data acquisition is essential for ergonomics analysis, human model development and model validation.

Accuracy of human motion acquired in experiments of ergonomics analysis is important. The biomechanical analyses of digital humans were firstly dependent on accurate postures and movements, secondly only perhaps to the validity of the analysis tools used (Chaffin, 2002). Videotaping has been widely used in traditional ergonomics analysis, and quantitative analysis of human movement, via video motion measurement, is a powerful means for addressing important ergonomics issues (Quesada, 1999); so the quality of the ergonomics analysis cannot be better than the quality of the motion data gathered from videotaping (Cochran et al. 1999). Rider (2004) has also mentioned the importance of the accuracy of motion data: The accurate and realistic representation of human behavior is one critical technical problem that should be solved before we can successfully implement the DHM into simulate human for ergonomics study. Also, among the 7 case studies of Chaffin's book (2001), 5 of them pointed out that the "deriving postures or motion for dynamic analyses from motion capture files" is one of the major limitations of current DHM technology.

Instead of using keyboard and mouse to simulate human motion, which is tiresome and error-prone task with the lack of validation, researchers have been thinking of two alternate methods to generate human motions: one is to use Motion Capture System to capture motion of real subjects, and based on that, motion can be predicted by motion models. Motion Capture (MOCAP) is an attractive method for creating the movement for computer simulation of human action because it can provide realistic motion, which contains the nuance and specific details of particular performers (Gleicher and Ferrier, 2002). And Chaffin (2002) has talked about modeling of human motion data can predict how different groups of people move in an environment and provide the ability to predict motions under conditions that are different than studied (i.e., one can extrapolate the data to analyze novel situations), but the creating of those models are still based on human motion captured from real subjects (Faraway, 1997; Chaffin 1999, 2000). By now, Motion Capture System has become an essential tool for ergonomics research and implementation.

Allard (1995) has summarized different human motion data acquisition methods and systems, which can be categorized into Video-Based Three-Dimensional Systems and Motion Capture Systems. Also, Motion Capture Systems can be categorized into three different types: Opto-electronic systems, non-optical systems including electromagnetic systems and ultrasonic systems, and medical imaging systems (Zhang and Chaffin, 2005). Table 1 shows the details of different kinds of motion capture systems.

Table 1

Summary of Different Kinds of MOCAP Systems

Category	Subcategory	Performance
Opto-electronic system	1. Passive system: markers are light-reflecting 2. Active system: markers are light-emitting	Opto-electronic system can achieve high efficacy, accuracy, and resolution, and do not have wired attached on subject. But it is expensive, and easy to be limited and influenced by environment. It is hard to be used out of lab.
Non-optical system	1. Electromagnetic system	Magnetic system can be used with fewer markers, and can capture movement of invisible body parts. But its sensors are relatively larger, and too easily to influenced by metals.
	2. Ultrasonic system	Ultrasonic system has least requirements about environment, but it is mainly used for simple motions of parts of body.
Medical imaging system		Medical imaging system is used for studying on real underlying skeletal kinematics with direct measurement of the body position and orientation. But it is only used to analyze static position.

Comparison of different motion capture systems have been done by researchers (Richards, 1999; Ehara, 1997), and we can know that opto-electronic systems have achieved great improvement on accuracy and resolution, which can now be used even for comparing finger movement. For this study, an opto-electronic system of Motion Analysis Company will be used. It is recognized that the accuracy of the motion capture system is affected by following factors: marker movement, sensor noise, restriction on environment, and frame rate. Also, the calibration of the motion capture system has a significant effect on the overall performance. A well-calibration is the basis for all motion capture work.

1.1.6 Virtual Environment

Virtual Environment (VE) is refereed to the 3D data set describing an environment based on real-world or abstract objects and data (Stanney, 2002). With current development of computer technology, VE has been widely used for the design and evaluation of future products and processes, because it can provide accurate and realistic representation of the real workspace. Wilson (1996) listed a number of areas where companies could benefit from VE including: job training, work aids, visualization and communication aid, in testing human-machine interfaces, and as a safe alternative to reality. Simulating objects or environments allows testing at early stages of development, thus reducing the guesswork and ensuring a quality product. More and more attention in ergonomic fields has been put on VE (Cerney et al., 2003, 2002; Davies, 1997).

Many commercial software have been developed, which can be used to build the virtual environment and create digital manikin to be inserted into the VE. Some of the software as RAMSIS, UGS JACK, and SAFEWORKS, are suitable for ergonomics analysis. The use of ergonomic knowledge to bring a new methodological credibility to many engineering projects based on VE is also growing steadily (Stone, 2002).

There are two main kinds of VE: immersive virtual environment and non-immersive virtual environment. For immersive virtual environment, people wear head-mounted stereo displays to provide full visual immersion and special gloves to get sex-degree-of freedom input for directly manipulating the environment. While non-immersive VE exposes the virtual world to human by means of conventional graphics workstation using a monitor, a keyboard and a mouse. Robertson (1993) has compared these two kinds of VE: in non-immersive VE, the scene is displayed with the same 3D depth curs used in immersive VE; full immersion is often seen as a major advantage, but the previous studies suggest that the same effect is possible with proper 3D cues and interactive animation for many applications due to some technical-related disadvantages of immersive VE, such as display jitter, time lag in six-degree-of-freedom input devices, display resolution. Also, Edwards (2004) has studied the using of various feedbacks in immersive virtual environment for manipulating tasks.

1.2 Virtual Interactive Design Methodology

In current world, products have to be designed and produced in shorter time period, and must be able to offer more convenience and safety to users; so many methods and ideas have been carried on to help. People begin to build virtual environment to contain and represent actual product or manufacturing work-cells, and create and insert avatars (virtual human) with specific anthropometry attributes into those virtual environments, as shown in Figure 2. Initially, people use some Inverse Kinematics Algorithms to calculate interested postures during special tasks, and then let the avatar to perform such postures in virtual environment to achieve simple simulations such as testing reach or sight line capability for a specific proportion of the population who might perform a task.

During the past several years, researchers kept on working on the development of dynamic ergonomics analysis; the key idea is to let the avatar "move" in the virtual environment. There are various sources to drive those avatars (Badler, 1997):

- Motion capture from direct live video
- Motion capture from sensors
- Pre-stored motion data
- As 2D sprites
- As 3D global transformations
- As 3D local (joint) transformations
- Motion synthesis
- Joint angle interpolation
- Inverse kinematics
- Dynamics
- Other generators (e.g. locomotion, faces)

Badler had continued analyzing different resources: pre-stored motion data are mainly used for replaying specific motions without generality and anthropometric extensibility; synthesis is a promising method, but inverse kinematics is not in itself an adequate model of human motion, and much more research is needed to build adequate human motion synthesis model; and since accurate human motion is difficult to synthesize, motion capture is a popular alternative; furthermore, by adding decision-making tools, it is hopeful to make virtual human be able to generate autonomous actions.

Chaffin (2005a, 2005b) and his group in HUMOSIM Laboratory at the University of Michigan (Faraway, 1997; Chaffin, 2000; Zhang, 2000; Dickerson, 2001; Kim, 2001, 2004; Park, 2004) mentioned several times about the human motion prediction model. They are working on building up an Integrated Dynamic Human Simulation Model, and one important part is to create Human Motion Simulation Model based on human motion captured by MOCAP system. This one will be carefully reviewed later. Since Integrated Dynamic Human Simulation Model can "automatically" generate motions for avatar in specific environment by human motion model, and achieve ergonomics analysis results by using biomechanical models, it is an ideal methodology for ergonomics analysis based on DHM, especially for testing new design, or new tasks in new environment. But it is still far away to complete perfect human motion models, especially for full-body motion prediction; since there are many other obstacles, so it is still meaningful to talk about using the motion captured by MOCAP system directly to drive avatars. Such integration of MOCAP and virtual environment with DHM, as well as DHM related ergonomics analysis tools is called virtual interactive design Methodology.

1.2.1 Virtual Interactive Design Methodology (VIDM)

In 2003, Virtual Build Methodology was proposed by Ford Auto Company, which integrates the DHM, MOCAP and VE together for ergonomic research (Brazier et al., 2003). After that, Li et al. (2006) initially introduced VIDM and examined seated reaching behavior for accessing an ATM by applying this methodology. The VIDM "synthesizes portions of the virtual interaction process, including visualization, data capture and engineering analysis, to enable design engineers the ability to gain objective feedback from the analysis of a users' interaction with the product during interaction" (Li et al, 2006). It is a systematic methodology for future proactive engineering or concurrent engineering concept.

In this methodology, an avatar related to biomechanical models will be created and inserted into virtual environment that represents the product or workplace interested. Then real human subjects will work in actual mockup or workplace, whose motion will be captured by MOCAP system and be used to drive avatar. Then the movement of that avatar will be used for ergonomics analysis automatically by connected biomechanical models. While, furthermore than just using MOCAP system to capture motions of subjects working in real mockup, motions may be captured by asking real people working in immersive virtual environment. This can be implemented by wiring head-mounted display, which will be showing virtual environment based on the orientation of the head of the subject and the vision calculated. Also, this is a real-time simulating system, which means that the avatar will move the same as the subject at the same time, and they will “see” the same environment, “reach” the same target, and “perform” the same movement.

Currently, the more practicable choice is to capture human motions when real subjects are working in actual mockup, and then use avatar driven by those motions in virtual environment for ergonomics analysis. This can be used in real manufacturing factory for device redesign or improvement, or be used after prototype been built up during design process. While in order to serve designers better, immersive virtual environment should be used to enable the simulation before prototype, which means considering ergonomics aspects in earlier design process.

The study of VIDM mainly considers the following two reasons:

1. Virtual Interactive Design Methodology may be a good alternation for application of ergonomics analysis in design process, especially before the development of applicable human motion model.

2. Also, Virtual Interactive Design environment serves the experimental environment for validation of human motion models.

Wu (2005) has summarized the integrated structure diagram of VIDM shown as Figure 4. In Figure 4, the dark solid line means physical connection and dash line means system internal features. The arrow shows the direction of information flow. The motion capture system tracks the human subject’s activity, and creates MOCAP marker model based on the human real motion. The motion capture system is connected with DHM & ergonomics analysis system. The MOCAP marker model is transferred to DHM & ergonomics analysis system to animate the digital human model, so that the digital human model can simulate the actual human subject. Then the DHM & ergonomics analysis system can conduct the ergonomic assessments based on the digital human model. The VE system provides the virtual view that the human subject interacts with. At certain situation, physical mockup is used instead of virtual environment, and human subject interacts with a physical mockup, which represents the workstation.

Based on the different integration setup, most previous Virtual Build-based ergonomic studies can be categorized into following three integrated levels:

1. DHM:

In traditional DHM analysis, people use two methods to set up the postures of avatar: one is using keyboard and mouse to manually move the joints and segments of the digital manikin, based on the observation of video of real human movement; the second one is using inverse kinematics algorithm to calculate the postures based on necessary inputs. These methods are lack of validity and reliability (Chaffin, 2005). While HUMOSIM lab in UM is working on the development of integrated dynamic human simulation model, which can really improve the using of DHM by generating human motions automatically without requiring the support of MOCAP system.

2. DHM + MOCAP + Mockup:

Because MOCAP technology can provide accurate motion data, which is recorded from actual human movement in real mockup, so this integrated level can provide accurate human motion interested. The most limitation of this integrated level comes from the limitation of MOCAP system, especially the influence from mockup and real workplace themselves. Also, the use of this integrated level requires the buildup of mockup or real workplace.

3. DHM + MOCAP + VE:

The integration of DHM, MOCAP and VE provides a theoretical sound solution for the ergonomics study in designing a future factory or redesigning an existing workspace. With the CAD data, one can build the virtual environment for the work station that needs to be studied, and through expose human into this virtual environment, motion capture can record the details of working, and then motion data can be imported into digital human modeling system to conduct the ergonomics assessments. We can then get the efficient assessment result.

There are some studies that have been done using the Virtual Build and Virtual Interactive Design methodology shown in Table 2.

Table 2

Literature of Using Virtual Interactive Design for Ergonomics

Author	Methodology	Purpose
Ford Company (Brazier, 2003)	DHM + Magnetic MOCAP	Vehicle Design
Ford Company (Brazier, 2004)	DHM + Magnetic MOCAP + VE	Auto assembly line Design
Miss. State Univ. (Li et al., 2005)	DHM + Optical MOCAP + VE	Design justification
Miss. State Univ. (Du et al., 2005)	DHM + Optical MOCAP	Assembly task Assessment

1.2.2 Setup of VIDM and Previous Validation

Tinghao Wu of CAVS at Mississippi State University has studied the reliability and validity of virtual interactive design methodology based on static ergonomics analysis results achieved from digital human manikin (Wu, 2005). Wu has described the need of validating VIDM, designed and set up the experiment, and analyzed the static ergonomics analysis results to test the reliability and validity of virtual build environment at HFE lab in CAVS.

Setup of VIDM

A virtual interactive design environment has been set up in CAVS at Mississippi State University, including Opto-electronic MOCAP system of Motion Analysis Company, UGS JACK software with various ergonomics analysis tool packages, 5DT Head-Mounted Display 800 with resolution of 800*600, and two IBM workstations separately for MOCAP server and UGS JACK DHM server. Following picture describes the instrument setup.

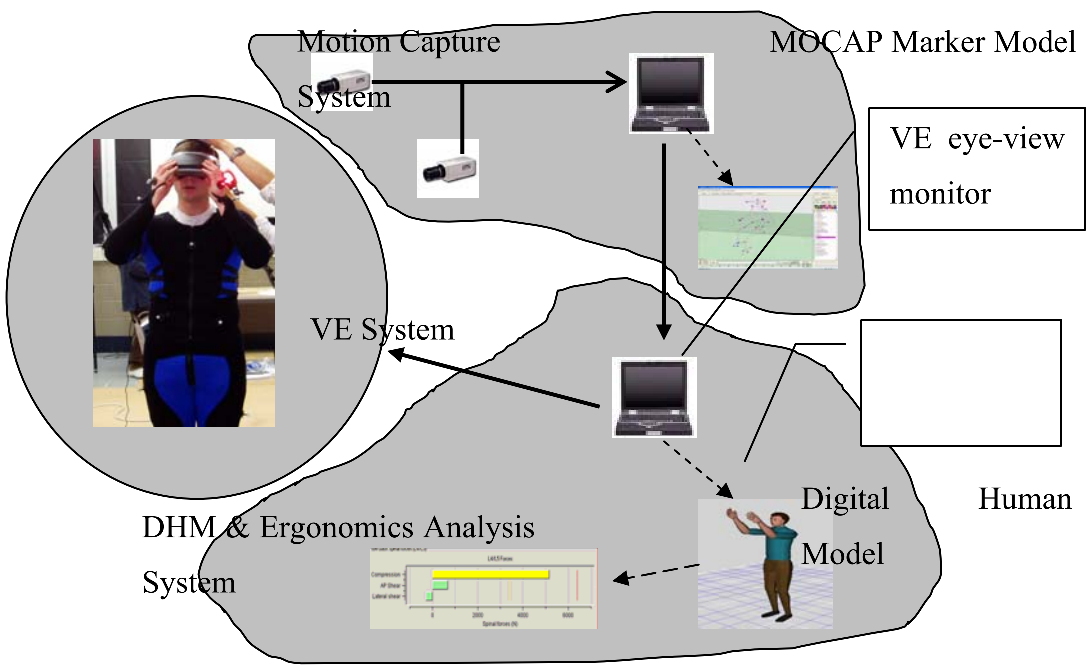

Figure 4

Integration structure diagram of virtual interactive design methodology

For the validation experiment, MOCAP system was calibrated on the volume with length of 3m, width of 2m and height of 2.5 m. The capture rate of the motion capture system was 60 frames per second.

The captured motion data was saved and streamed into JACK system, in which digital manikin model and virtual environment were created. The head-mounted display was connected with JACK to expose the virtual environment to subjects.

Validity and Reliability Test of VBE

Leo's validation used the criterion-method, and the comparing unit was the analysis result of NIOSH. He manually controlled the DHM in Jack to complete those actions, and got the NIOSH analysis results for each subject, which will be used as STANDARD. Then for each subject, NOISH analysis results could be got by inputting the motion data captured from human subjects, both in VE and Mockup. At last, all these NOISH results were compared with those standard data in order to check the validity of that integrated system

In Leo's research, test-retest method was used to evaluate the reliability of the three-level integrated system. For each action of each subject, there was a pair of motion data which is corresponding to two different trials. Ergonomics analysis results can be obtained by inputting these pairs of motion data into Jack software, and they can be compared to calculate the *ICC*, which will be used to judge the reliability of system represented as over-time consistency.

1.3 Validity and Reliability

Validity and reliability are two main aspects this study will work on the Virtual Build methodology.

1.3.1 Validity

Validity refers to the accuracy of a measurement. A valid measurement should measure what it intends to do, and this accuracy can be represented in degrees. Generally, there are four methods that can be used to measure the validity, while this study will focus on the criterion-related validation. This means that I will define a standard criterion which can be believed as valid measurement and then compare other measurements with this one to validate them.

1.3.2 Reliability

Reliability refers to the ability of a measurement get the same results in repetitive tests, which will greatly affect the level of validity, and which is prerequisite for a valid measurement (Fagarasanu et al., 2002). There are also a few of methods that can be used to check the reliability of a method, while in this study, test-retest method will be used in order to check the consistency of the integrated methodology in terms of time. It is generally thought that test-retest is more costly than the others, but it is a simple and clear reliability method (Hager, 2003). In order to that, subjects will be required to do the same actions in exact the same condition twice in different time, and data of two trials will be compared.

CHAPTER II

RESEARCH OBJECTIVE

2.1 Research Objective and Process

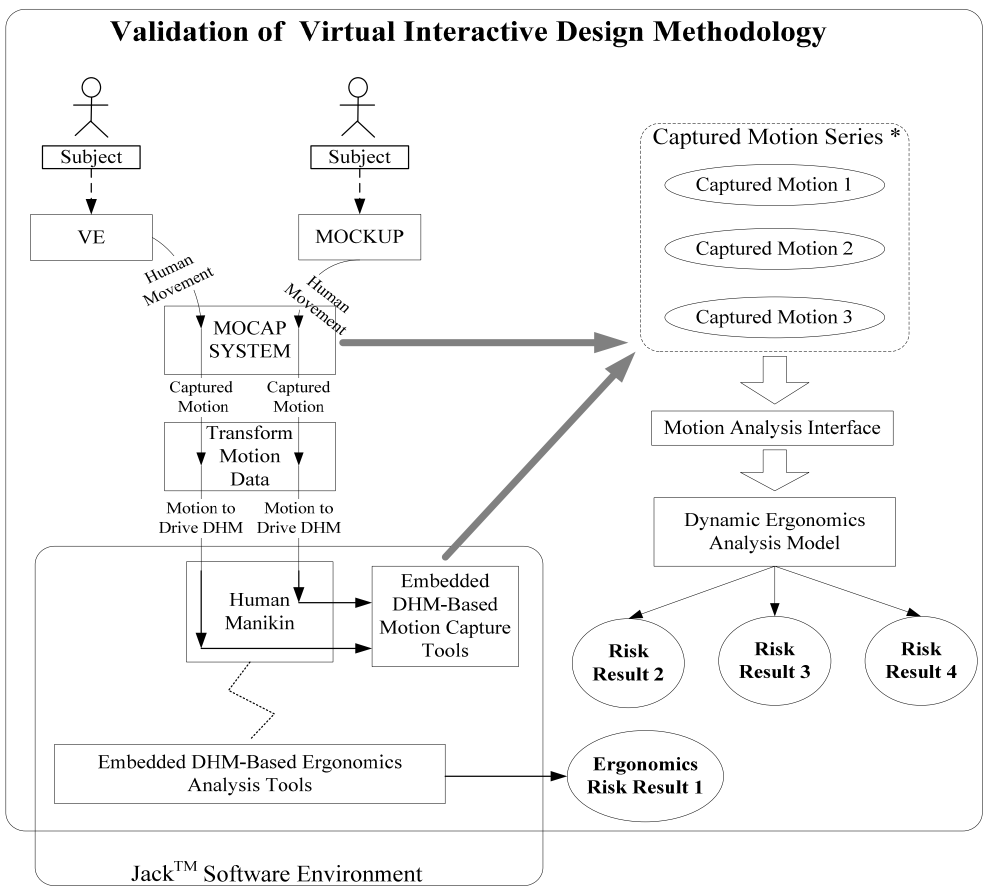

Figure 5

Research purpose and process

There are many researches that have been done on studying the accuracy or fidelity of DHM, MOCAP or VE individually, but the validity of whole integrated system is still insufficient. Especially for the ergonomics study, accurate description of the human and environment, valid motion and interaction are very important.

Also, reliability plays important roles in using virtual interactive design environment for practice in enterprises and ergonomics analysis. Few researches have been done on this problem. Lower reliability of measures may negatively affect the validity of measures. This study will focus on the over time reliability and alternative reliability of the virtual build methodology in conducting ergonomics analyses. Test-rest experiment will be used for reliability test.

Research objective of this study is to test the validity and reliability of the virtual interactive design methodology based on dynamic ergonomics analysis. In order to do that, dynamic ergonomics analysis tool is integrated into virtual interactive design environment instead of previous static tools.

Figure 5 shows the process of this study. Firstly, subjects are required to perform some tasks in both the actual mockup and corresponding identical virtual environment, and their movements are captured through motion capture system. Those captured motions are input into Jack Software to drive the digital human manikin, who will perform the acts the same as subjects. Then the embedded static ergonomics analysis tools in Jack are used to analysis the risk for the actions performed by the human manikin, which is recorded as “ergonomics risk result 1”. Also, an embedded motion capture tool in Jack is used to capture the movement of human manikin. Motions captured by this tool and motions captured by motion capture system directly from subject are summarized as captured motion series:

1. Captured Motion one represents the mockup-based motion performed by real subject which is captured by Motion Capture System. Subjects performed tasks in both mockup and virtual environment, and both kinds of motions are input into Jack to drive human manikin; but only the motion performed in mockup will be used for dynamic ergonomics analysis as standard.

2. Captured Motion two represents the mockup-based motion performed by Digital Human Manikin in Jack software which is captured by Jack-embedded motion capture tools. After the motion of subjects acting in mockup is used to drive human manikin, actions of that avatar are also captured using some tools and recorded for dynamic ergonomics analysis.

3. Capture Motion three represents the VE-based motion performed by Digital Human Manikin in Jack software which is captured by Jack-embedded motion capture tools. After the motion of subjects acting in virtual environment is used to drive human manikin, actions of that avatar are captured using some tools and recorded for dynamic ergonomics analysis, too.

All of above series of motions are analyzed to achieve necessary dynamic information, and a dynamic ergonomics analysis model is applied to generate ergonomics risk results corresponding to different series. Risk Result two is related to Captured Motion one, Risk Result three is related to Captured Motion two, and Risk Result four is related to Captured Motion three. Risk Result one and two are used as standard respectively, and some comparisons between those analysis results are implemented for the validation purpose and will be explained in detail later.

2.2 Advantages and Disadvantages of Previous Study

Wu (2005) studied the validity and reliability of the virtual build integrated system last year, which included the following main parts.

2.2.1 Validation

Wu's validation used the criterion-method, and the comparing unit was the analysis result of NIOSH. He manually controlled the DHM in Jack to complete those actions, and got the NIOSH analysis results for each subject, which will be used as STANDARD. Then for each subject, NOISH analysis results could be got by inputting the motion data captured from human subjects, both in VE and Mockup. At last, all these NOISH results were compared with those standard data in order to check the validity of that integrated system.

2.2.2 Reliability

In Wu's research, test-retest method was used to evaluate the reliability of the three-level integrated system. For each action of each subject, there was a pair of motion data which is corresponding to two different trials. Ergonomics analysis results can be obtained by inputting these pairs of motion data into Jack software, and they can be compared to calculate the *ICC*, which will be used to judge the reliability of system represented as over-time consistency.

2.2.3 Sensitivity

Wu conducted a series of ANOVA to study effects of anthropometric input and external loads on virtual build separately. For testing anthropometric input, he scaled digital manikin by 5 different statures, and then using motion from each subject in each trial to drive the manikin for NOISH analyses (NOISH is not related to anthropometric input itself). Then the results are studied. Also, he studied the effects of external loads on Virtual Build and system reliability

2.2.4 Problems in Previous Study

There are several problems or insufficiencies in this research.

1. Only static analysis tools embedded in Jack software were implemented, including NOISH, RULA and SSP. Since all ergonomics analysis tools used are posture-based, no comparing unit is obtained with considering dynamic information. But dynamic factors play a important role in ergonomics risks, so only posture-based validation is not sufficient.

2. As a posture-based validation, selection of posture is most important to ensure the precision. While since all those static postures in Wu's validation are chosen manually, control and operation of researchers will greatly influence the final analysis results. This may increase the uncertainty of validation process.

3. Wu's validation of this three level integrated system is based on the hypothesis that analysis results of manually setup postures are correct, and comparisons are applied between other analysis results and this assumed standard. Also, analysis tools of Jack have been used, and their analysis results can not be guaranteed to represent real situation, which results in bringing more influent factors into the testing process.

4. It is difficult to find problems. Although the final results can represent the validity and reliability in some sense, it is difficult to say more details about the problems and reasons which cause those disadvantages of final results.

5. His sensitivity analysis has one key problem is that he used enacted stature values to scale the manikin, but drove the human model by captured human motions; this will not be an analysis based on valid real human model.

So, it is necessary to implement new study on this problem.

CHAPTER III

ANALYSIS METHODOLOGY

3.1 Dynamic Virtual Interactive Design (DVID) Environment

3.1.1 Integrated System

Based original static VID environment, a dynamic virtual interactive design environment is constructed in this study. Following figure 6 shows the structure of dynamic VID environment.

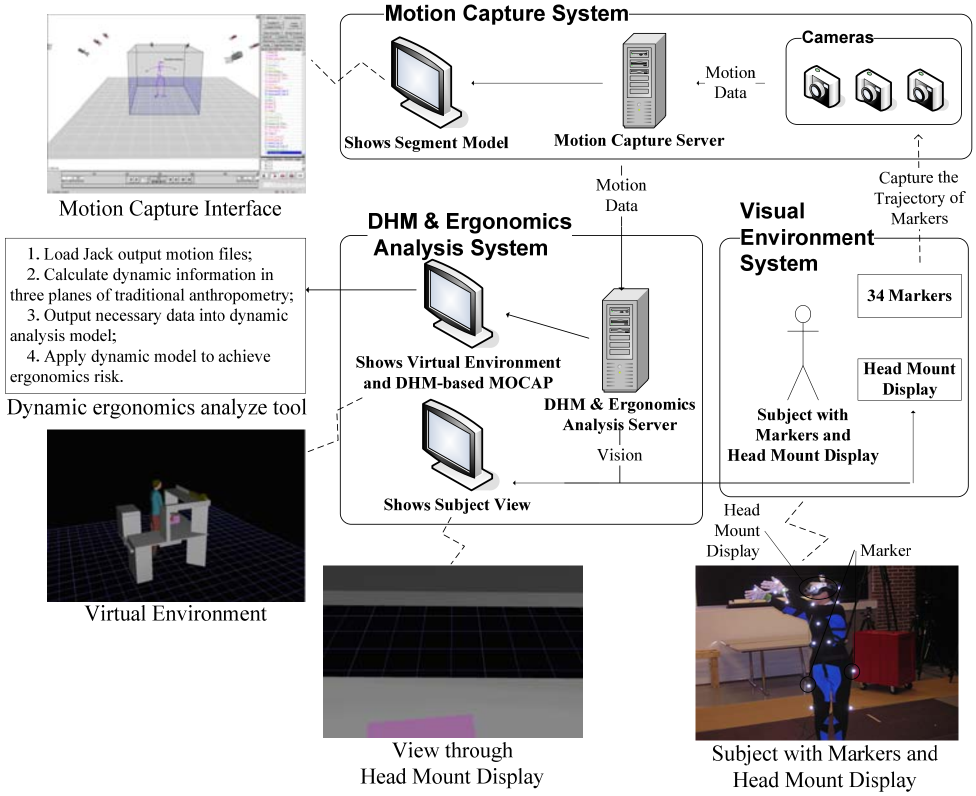

Figure 6

Structure of dynamic virtual interactive design environment

The integrated system is mainly composed of four parts:

1. Center part is the visual environment system, where subjects with markers and head mount display can perform actions both in mockup or in Immersive VE by viewing through head mount display.

2. Motion capture system can capture the movement of subjects by recording the trace of all markers.

3. DHM & Ergonomics server is taking charge in offering human manikin and the virtual environment. Current DHM used in our VID system is Jack environment, composed with human manikin driven by MOCAP output synchronously, virtual environment, and some tools like imbedded ergonomics tools and motion recorder. It can offer animation of human motion, immersive virtual environment for subjects, and manikin-related ergonomics analysis like some static ones as SSP, NIOSH and RULA. Also, Jack can capture the movement of human manikin and output into files.

4. Dynamic ergonomics analysis tool is composed of the interface to achieve dynamic information from Jack output and the dynamic ergonomics model constructed by Marras (1993). Following section will describe the dynamic ergonomics analysis tool.

3.1.2 Dynamic Ergonomics Analysis Tool

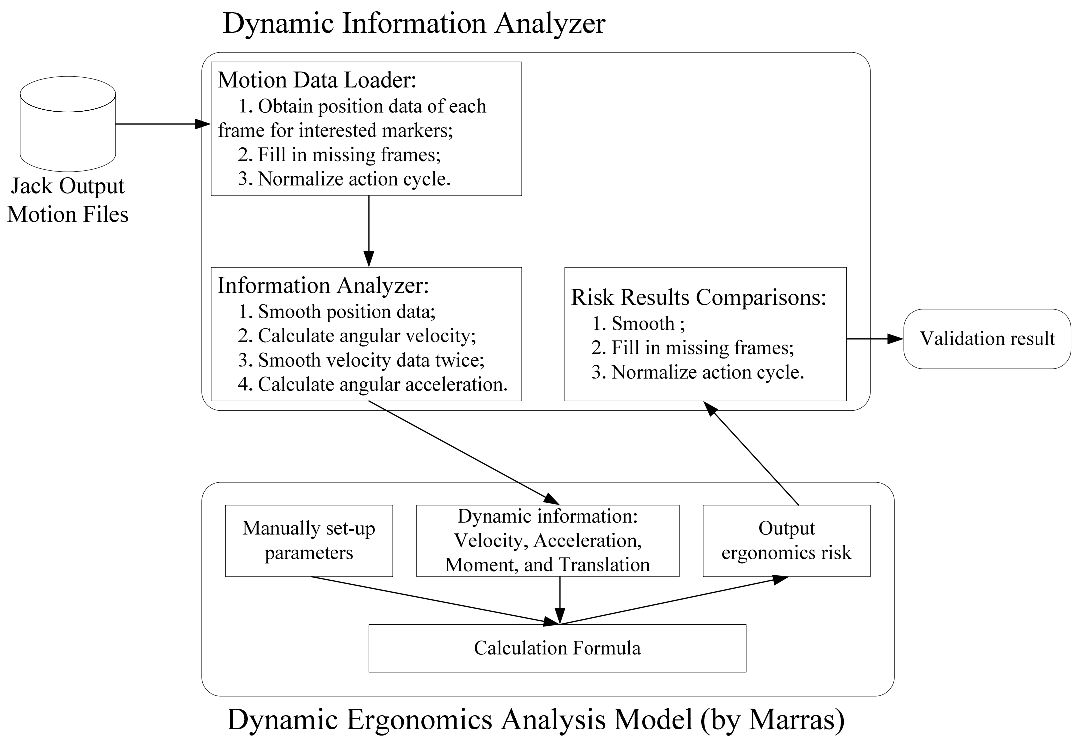

Figure 7

Dynamic ergonomics analysis tool

As shown in above figure, dynamic ergonomics analysis tool used in this study is mainly composed of two parts.

Dynamic Ergonomics Analysis Model

The Job Risk Classification Model (JRCM) (Marras et al, 1993) has been shown to work well with MOCAP output (Cappelli and Duffy, 2006). This model uses various trunk motion and workplace factors to predict probability of high-risk job classification.

JRCM is a multiple regression model which can discriminate high and low risk lift task by calculating a risk number for each task. This model mainly consider trunk motion and some other related information during lift actions, parameters and corresponding coefficients used are shown in following table 3 (Marras et al, 1993).

Table 3
JRCM Parameters and Coefficients

Parameter	Coefficient
Constant	-3.80
Lift Rate (LR)	0.0014
Maximum Moment (MM)	0.024
Maximum Sagittal Flexion (MSF)	0.020
Average Twisting Velocity (ATV)	0.061
Maximum Lateral Velocity (MLV)	0.036

So for each task, a risk value will be calculated and normalized using the formula below:

$$R = -3.8 + 0.0014 * LR + 0.024 * MM + 0.02 * MSF + 0.061 * ATV + 0.036 * MLV$$

Estimated logistic probability: $\hat{R} = \dfrac{e^{-R}}{1 + e^{-R}}$

Dynamic Information Analyzer

Shown as figure 7, this part takes charge of three main functions: load motion data from Jack output file, analyze those motion data to achieve necessary dynamic information and output that information into JRCM, and then get the calculation results from JRCM and implement comparisons between ergonomics risk numbers for validation of the whole system. Here are important points.

1. Motion data loading part. When retrieving position data, there are some missing frame where no position information available. In that case, those empties should be fulfilled by average the position coordinates of nearby frames. Loaded motion data are imported into Excel.

2. Motion data analysis part. This part uses VBA in Excel to process motion data. A seven-point smoothing routine is used to smooth data by the following formula:

For every seven continuous position data set X = x[1, x2, ..., x7], assume $X \sim N(\mu, \sigma^2)$
$F(x)$ is the normal distribution for the specified mean (μ) and standard deviation (σ).

$$\therefore \tilde{x}_4 = \frac{F(x_1)*x_1 + F(x_2)*x_2 + F(x_3)*x_3 + F(x_4)*x_4 + (1-F(x_5))*x_5 + (1-F(x_6))*x_6 + (1-F(x_7))*x_7}{F(x_1) + F(x_{21}) + F(x_3) + F(x_4) + (1-F(x_5)) + (1-F(x_6)) + (1-F(x_7))}$$

Dealing with the loaded position data, one cycle of data smooth is applied, and smoothed position data are used to calculate translation. Then translation data are smoothed twice, and then smoothed translation data are used to calculate velocity. Finally, velocity data are smoothed twice to calculate acceleration information.

Calculated dynamic information is then input into JRCM to calculate ergonomics risk for tasks.

3. Risk results comparisons. This part imports analysis results from JRCM and save in Excel Worksheets. And then for each motion trials, some comparisons between standard series of risk results and interested series of risk results are applied for validation purpose. Several kinds of statistics analysis tools are used here.

3.1.3 Data Flow of DVID Environment

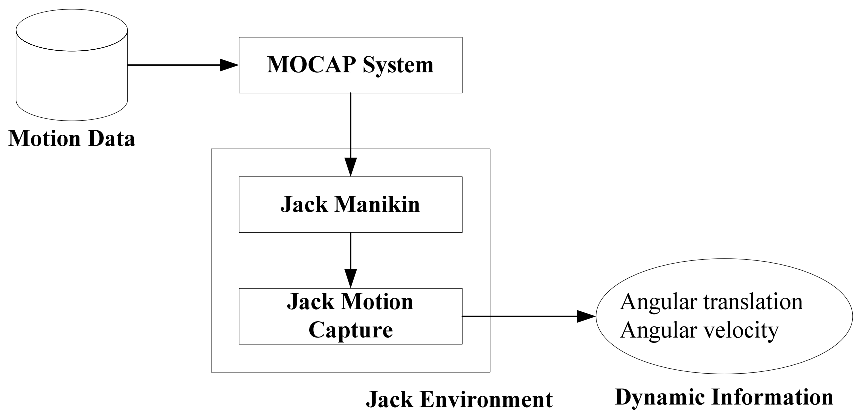

Figure 8

Data flow of DVID

Process to evaluate task risk through dynamic VID environment includes following 4 steps:

1. Load motion data of special task into MOCAP system: in Motion Capture system, task movement of one subject is recorded in a file as a series of postures, where each posture is described as positions of all the markers put on that subject; these files of all subjects can be loaded and drive rigid human model to act.

2. Connect Jack manikin to MOCAP system, and let Jack human model act as MOCAP rigid model acts: a interface between UGS-Jack™ and MOCAP is used here to keep Jack manikin moving synchronically with the rigid human model in MOCAP system by calculating translations and rotations of the more than 100 joints although Jack DHM based on the position of those pre-defined markers.

3. Capture the movement of manikin using motion recorder embedded in Jack system: Jack environment offers a motion recorder tool to capture movement of Jack manikin in real time, and real and virtual markers can be added on that manikin to record their position information during capture process.

4. Calculate necessary information for JRCM by analyzing Jack output motion file. The Jack output motion file consists of two sections: the first section includes all the rotation information about body joints; the second section includes all the position information of markers attached on the body. Positions of necessary markers related to trunk motion are investigated in this study to calculate JRCM-needed values, while data-smooth filers are applied during the calculation.

3.2 Experimental Design

3.2.1 Participants

Total of 36 human participants were invited to take part in this study. Those participants were recruited by advertisement in campus of Mississippi State University. Participants can cover 95 percentile male to 5 percentile female. All of participants are screened of the musculoskeletal disorder history and motion sickness. Each subject did 6 different actions twice in each environment (VE and Mockup), which means that each subject will do 24 actions with 12 in VE environment and others in mockup environment. Here, the VE means that the human subjects will act in a build-in virtual environment without any real stuff there, by watching environment and interactive hints through head-mounted displayer. Tasks will be described later.

3.2.2 Instruments

A 8-cameras optical motion capture system by Motion Analysis company will be used in this research with frequency of 60Hz. 1 Motion Capture server will be used to run Motion Analysis Software and offer motion data, and 1 DHM server will be used to run UGS Jack software including digital human manikin and virtual environment. Embedded ergonomics analysis tools in Jack will be used to perform ergonomics analysis. A 5DT head-mounted display with resolution of 800*600 will be connected with DHM server to get virtual vision, and then expose Virtual Environment and simulated interaction to human subjects.

3.2.3 Description of Experiment

The goal of this experiment is to test validity and reliability of virtual build methodology, so both virtual environment and mockup of exactly same size were constructed. Four different kinds of tasks including Front Lifting (FL), Side Lifting (SL), Standing Forward Reaching (SFR) and Horizontal Pushing (HP) were involved; also, different external loads were set for Front Lifting including 0lb, 1lb, and 20lbs, so totally there were 6 tasks (0 lb FL, 1 lb FL, 20 lb FL, SL, SFR, and HP). Each task was performed by each subject twice in both environments (totally 6*2*2=24 tasks for each subject). Table 4 shows the detailed information.

Table 4

Summary of Tasks

Environment	Task	Load	Trial	No
Mockup	Front Lifting	0 lb	1/2	1
		1 lb	1/2	2
		20 lbs	1/2	3
	Side Lifting	0 lb	1/2	4
	Forward Reaching		1/2	5
	Horizontal Pushing		1/2	6
Virtual Environment	Front Lifting	0 lb	1/2	7
		1 lb	1/2	8
		20 lbs	1/2	9
	Side Lifting	0 lb	1/2	10
	Forward Reaching		1/2	11
	Horizontal Pushing		1/2	12

For each subject, sequence of environments was randomly decided, and then 6 tasks were randomly assigned in each environment. Each subject performed each task twice, and all 24 series of motion data were collected. All motion data then were used to driven Jack manikin and corresponding ergonomics analysis results were got, shown in table 5.

Table 5

Summary of Ergonomics Analysis Tools

Task	External Load	Ergonomics Analysis Tools
Front Lifting	0 lb	NOISH/SSP
	1 lb	NOISH/SSP
	20 lbs	NOISH/SSP
Side Lifting	0 lb	NOISH/SSP
Forward Reaching		RULA
Horizontal Pushing		SSP

3.2.4 Description of Motion Data

MOCAP system is connected to Jack software, and each trial of motion data captured by MOCAP are input into Jack to drive the manikin. Then motion capture tools embedded in Jack are used to capture the movement of that manikin, and channelset files are saved to store those motion data, shown as figure 9.

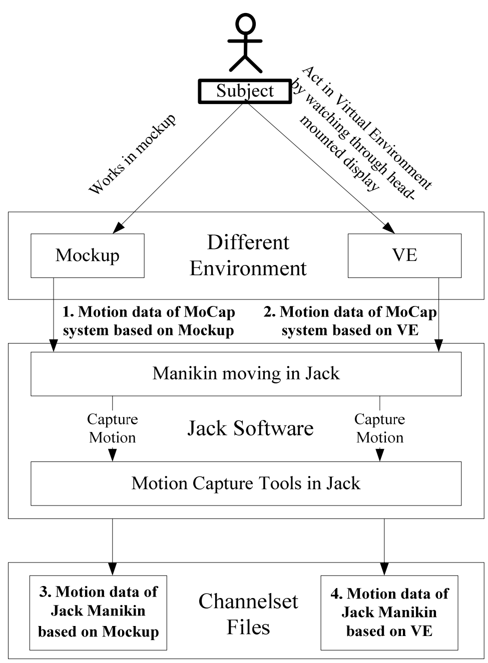

Figure 9

Summary of all four different kinds of motions

The 4 sets of motion data include:

1. Motion data of MoCap system based on Mockup;
2. Motion data of MoCap system based on VE;
3. Motion data of Jack Manikin based on Mockup;
4. Motion data of Jack Manikin based on VE.

3.3 Comparison Methods

Purpose of this study is to test the integrated system, which includes MOCAP system working with both mockup and VE, the digital human manikin working in Jack, and dynamic ergonomics analysis model. The final purpose is to know if the VE+MOCAP+DHM+JRCM integration can work well for representing real subject motion in actual workplace and be used for analyzing ergonomics risk. All possible errors in this environment are shown in figure 10.

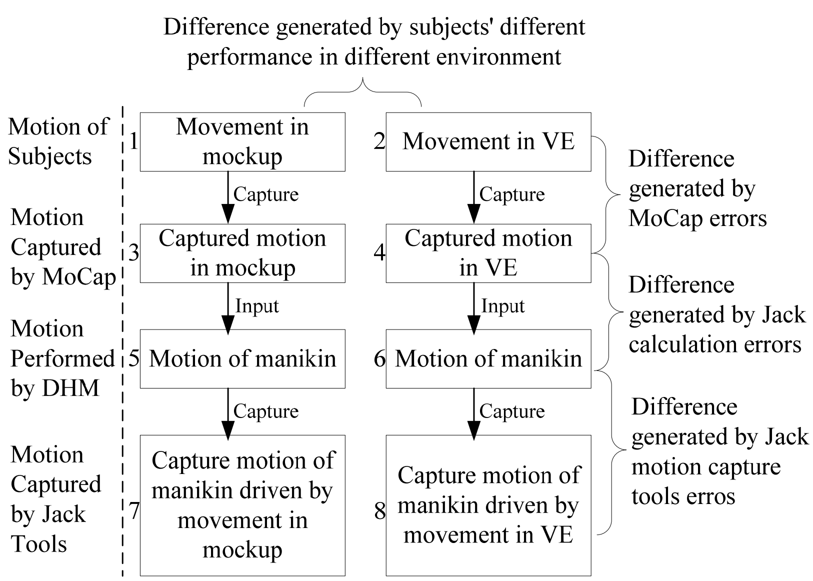

Figure 10

All possible errors in integrated DVID environment

As shown in the figure, errors include several parts for this three-level structure.

1. Error generated by the different actions performed by subjects in Mockup and VE

2. Error of the MOCAP System

3. Error of the conversion from motion data from MOCAP to movement of Jack manikin

4. Error of the jack motion-capture tools.

The error of MOCAP is not interested in this study, while the following three parts will be studied. Generally, the motion of human in mockup should be regarded as the standard and be used to validate others; since these data are not available directly, so I will use the dynamic ergonomics analysis results from captured motion data of human performance in mockup as standard (No. 3 in figure 10), and the MOCAP system will be assumed to be valid and reliable.

Error generated by the difference between Mockup and VE is a main influence factor in integrated system, and the two errors related to Jack can be regarded together as Jack error. In following parts, comparing pairs for testing validity, reliability and sensitivity in all these data will be studied, and those two kinds of errors will be analyzed too.

3.3.1 Validity

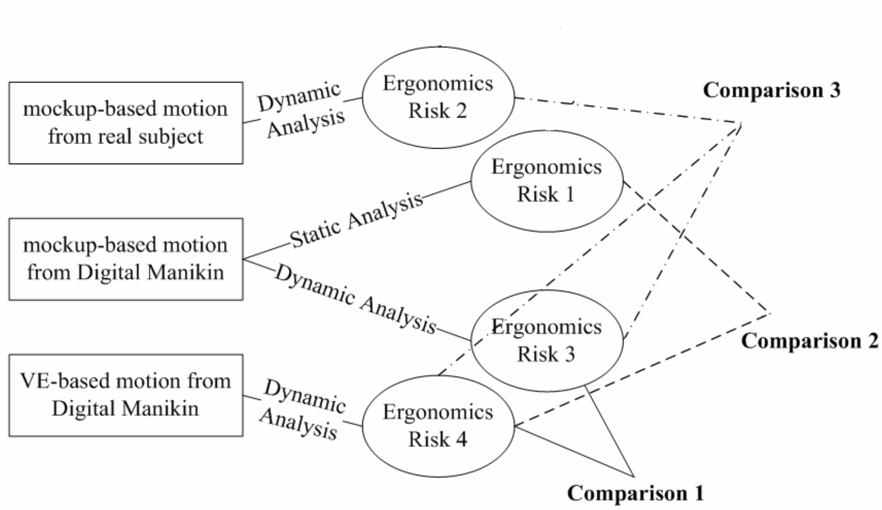

Figure 11

Validation comparison pairs

To test the validity, the analysis results of JRCM from following pairs of motion data sets will be compared, shown as figure 11

1. Comparison between Ergonomics Risk 3 and Ergonomics Risk 4. This means that integration of VE+MOCAP+DHM+JRCM is compared with integration of Mockup+ MOCAP+DHM+JRCM. By doing this, we can examine the bias generated by subjects' different performance in mockup and VE. This comparison result can directly judge if the VE integration can be used, since Mockup based movement is accurate.

2. Comparison between Ergonomics Risk 1 and Risk 3, 4. Mockup-based motion from Digital Human manikin has been proved to be accurate enough for static ergonomics analysis, whose result is recorded as Ergonomics Risk 1. So Ergonomics Risk 1 can be used as one standard to test other two Risks.

3. Comparison between Ergonomics Risk 2 and Risk 3, 4. Ergonomics Risk 2 is another standard used in this study. Since mockup-based motion from subjects is assumed to be accurate, so the dynamic ergonomics analysis on this kind of motion can be treated as a good standard for validating all other kinds of dynamic ergonomics analysis.

3.3.2 Reliability

Test of the reliability will base on the test-retest method, and will be applied on motion of manikin based on both environments. Since all the tasks have been done twice, all the four kinds of motions between two trials for each task of each subject should be compared to test the reliability.

3.4 Data Analysis

3.4.1 JRCM Input Definition

As described above, calculation of JRCM requires several input of dynamic information. In following formula:

$$R = -3.8 + 0.0014 * LR + 0.024 * MM + 0.02 * MSF + 0.061 * ATV + 0.036 * MLV$$

LR is lifting rate which can be manually set up. All the other four need to be calculated from dynamic motions. MM is maxim moment, MSF is maximum sagittal Flexion, ATV is average twisting velocity, and MLV is maximum lateral velocity. Here, the three reference planes in conventional anthropometry are used. Sagittal plane is the plane in the middle which divides person into left part and right part, and MSF means the maximum forwarding bend of the subject during the whole action. Coronal plane the plane in the middle which divides person into front part and rear part, and MLV is the maximum siding bending angular velocity in coronal plane. Transverse plane is the plane which is vertical to the other two planes, and ATV is the average twisting angular velocity in this plane. All the planes are shown as figure 12.

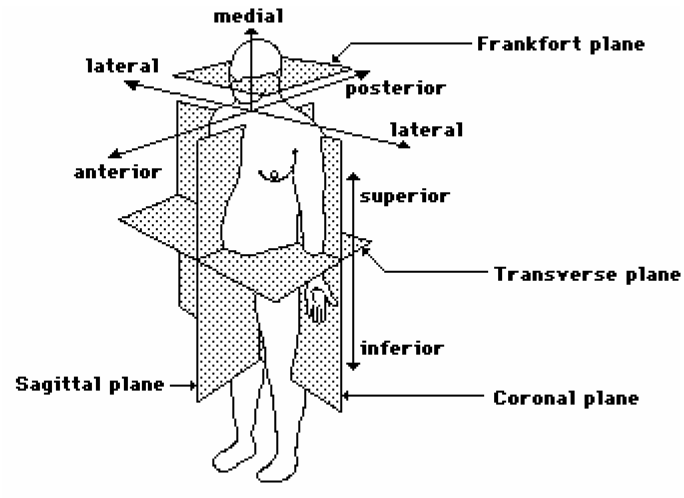

Figure 12
Reference planes in traditional anthropometry

Jack market set is used in both MOCAP system and Jack motion capture tools, and thus the motion records in all output files are represented by position data of all markers. Jack market set placement is in Appendix A. In order to use markers to calculate dynamic information, following algorithm is applied.

Since JRCM is focusing on trunk motion, it is important to define two endings of trunk. In Jack market set, PSIS_R and PSIS_L are two markers on rear waist side, and their center point can be used to represent bottom ending of trunk; NECK_BASE_REAR can be used to represent top ending of trunk. Calculation of MSF and MLV is based on the position data of these three markers.

For calculating ATV, the other two markers are used, which are Acromion_L and Acromion_R. These two markers are attached on left and right shoulder. By checking the change of the position data of them, twisting velocity of trunk can be got.

For calculating MM, we need the distance between load and trunk. So visual markers of Left_Hand_Palm and Right_Hand_Palm are used to decide the position of load, and PSIS_R and PSIS_L are also used to decide position of trunk.

3.4.2 Data File Description

Shown as above, four kinds of data will be considered into this study, and they are saved in two different kinds of files.

Motion Data of MOCAP System:

Data are saved in ".trc" files, and all the position information of sites are stored based on time and frames. These sites are standard which are all well defined and the same as those used in Jack software.

Motion Data of Jack:

Motion data of Jack are saved in channelset files. Three kinds of data are stored.

First of all, there must be a reference site, whose position and orientation will both be recorded; and this one is used as the root to judge position and orientation of the whole body. Without any other information, the manikin will be regarded as a bar that moves and rotates driven by this information.

Then there must be information saved about the rotation of main joints of that manikin. All this information is based on local coordination at each joint, so it is not a good choice to compare this information.

By adding sites into captured contents before capture manikin's motion, we can get the global positions of all sites in channelset files. These sites are the same as those used in MOCAP system, although they are based on different coordination.

3.4.3 Preprocess of Motion Data

Markers Selection and Motion Data Import

Position data of the markers mentioned above are imported into Jack worksheet for each frame of each subject. Missing data are added by averaging nearby data.

Motion Process Standardization

Since generally different trials of motion cycle have different frames, so all the motion cycle should be standardized firstly before analysis. I will assume the motion trends between two frames are linear to calculate the motion data between frames, and furthermore standardize all the motion trials into standard length of frames.

Coordination Unification

Since the motion captured by MOCAP system is using the different coordination from the motion data of manikin recorded in Jack software, unification of coordination should be applied before comparison. They have the same X axis, while $Z_{Jack} = -Y_{MOCAP}$, and $Y_{Jack} = Z_{MOCAP}$.

Relative Motion Data Calculation

Relative motion data will be used in this study. Instead of using motion data saved in ".trc" or channelset files directly, I will calculate all the relative data based on the initial frame. This means that translation from beginning frame instead of absolute position will be used for further calculating.

Programs are developed to help performing above operations.

3.4.4 Data Analysis

Shown as previous figure 11, three kinds of comparisons among analysis results are applied to test the validity and reliability. These three comparisons include: Mockup-based dynamic analysis method versus VE-based dynamic analysis method, DHM-based dynamic analysis method versus MOCAP-based dynamic analysis method, and VE-based dynamic analysis method versus Posture-based static analysis method. All the analysis methods involved in those comparisons are shown in figure 13.

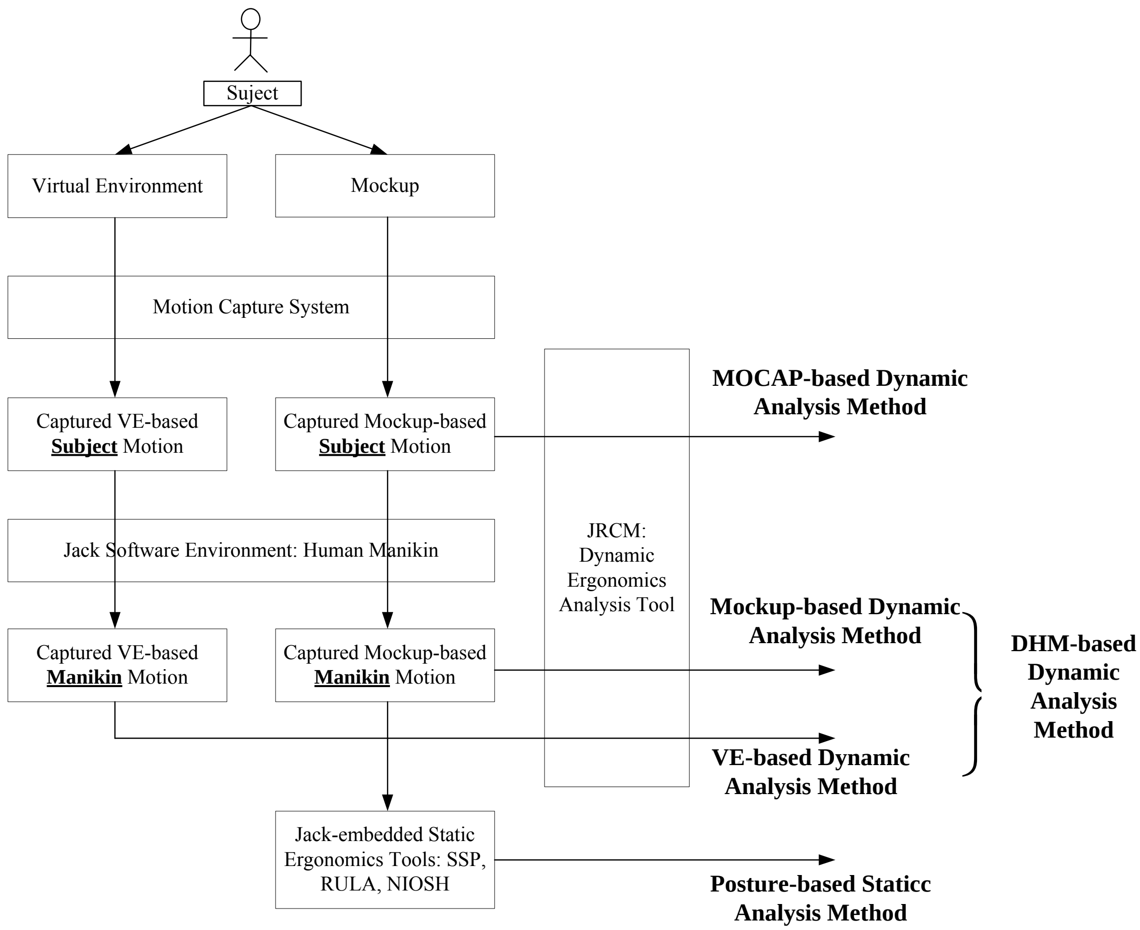

Figure 13

All kinds of analysis methods

<u>Analysis Methods</u>

Shown as figure 13, there are five methods defined in this study.

Mockup-based dynamic analysis method is trying to use JRCM to analyze movement of DHM driven by motions of subject when acting in mockup. Shown in figure 13, this analysis method includes 4 steps: capture subject-movements when they are acting in mockup, transform those movements and drive human manikin using those movements, capture manikin-movements when they are driven to act, and analyze manikin-movements using JRCM to get risk prediction for some tasks.

VE-based dynamic analysis method is trying to use JRCM to analyze movement of DHM driven by motions of subject when acting in VE. This method includes similar steps as mockup-based method, while the main difference is to capture subject-movements when try are acting in VE.

DHM-based dynamic analysis method includes the above two methods. Since both mockup-based method and VE-based method are using JRCM to analyze movements of manikin, so they can be called DHM-based dynamic analysis method.

MOCAP-based dynamic analysis method is trying to use JRCM to analyze movement of subject captured by MOCAP system when acting in mockup. Different from above methods, MOCAP-based method uses JRCM to analyze movement of subjects when they are acting in mockup. These movements are supposed to be accurate enough.

Posture-based static analysis method is trying to use some Jack-embedded static ergonomics analysis tools like SSP, RULA, and NIOSH to analyze movements of manikin. These movements are captured when manikin is driven by movements of subjects when they are acting in mockup.

<u>Comparison Pairs</u>

1. Comparison one: Mockup-based method vs. VE-based method

These two methods are all based on the analysis of manikin-movements, and the only difference is that the driven movements are captured in different environments. As mentioned above, there are some errors generated by subjects' different performances in mockup and VE in DVID environment. By comparing these two methods, I am trying to examine this kind of error. In other words, I want to check if VE can be used to replace mockup when we want to capture movements of subjects for analyzing risks of special tasks; and the analysis is based on dynamic information. So, following hypothesizes are tested:

H0: Difference between mean dynamic ergonomics analysis results of both mockup-based dynamic analysis method and VE-based dynamic analysis method for each task should be equal to 0.

H0: Difference between dynamic ergonomics analysis results of both mockup-based dynamic analysis method and VE-based dynamic analysis method for each subject to perform each task should be equal to 0 or can be fixed.

If we can prove above null hypothesis, we can say that VE can be used to replace mockup when using DVID environment directly, or after some calibration.

2. Comparison two: Posture-based method vs. VE-based method

Analysis results of posture-based method have been proved to be valid and reliable in previous study. In this kind of comparisons, posture-based analysis results are regarded as standard, and I am trying to prove the validity of VE-based analysis method. But since output format of JRCM is quite different from those from those static tools, following hypothesis will be tested:

H0: VE-based dynamic analysis outputs are representing similar risk information (mean risk value) for each task as static analysis outputs.

3. Comparison three: DHM-based method vs. MOCAP-based method

Mockup-based dynamic analysis method and VE-based dynamic analysis method are the two methods that are based on movements of human manikin; however, MOCAP-based analysis is based on the movements of subjects. This comparison contains two purposes:

1. As mentioned above, there are some errors generated by Jack environment. Since MOCAP-based method and mockup-based method are all based on motions from mockup, comparison between them can examine the errors generated by Jack;
2. Subject-movements that are captured when they are acting in mockup are supposed to be exact representation of real human motions, so the analysis on them can be regarded as most exact and valid; then validity of DHM-based method can be tested by applying this comparison.

Hypotheses that will be tested include:

H0: Difference between mean outputs of DHM-based dynamic ergonomics analysis and mean outputs of MOCAP-based dynamic ergonomics analysis for each task should be equal to 0.

H0: Difference between dynamic ergonomics analysis results of both DHM-based dynamic analysis method and MOCAP-based dynamic analysis method for each subject to perform each task should be equal to 0 or can be fixed.

4. Comparison via two trials

Reliability of mockup-based analysis outputs and VE-based analysis outputs is examined by comparing their outputs via two trials for each task performed by each subject. If these two methods are reliable, their outputs for each trial should be the same. So test hypotheses are:

H0: Difference between two-trials of VE-based dynamic ergonomics analysis results for each subject for each task is 0.

H0: Difference between two-trials of mockup-based dynamic ergonomics analysis results for each subject for each task is 0.

CHAPTER IV

ANALYSIS RESULTS

In this chapter, risk results for tasks performed by each subject will be calculated, summarized and analyzed, and corresponding information like velocity, moment and translation needed for the dynamic ergonomics model will be analyzed, too. Based on the hypothesis proposed in last section, various comparisons are categorized.

4.1 VE-based vs. Mockup-based Dynamic Analysis Results

Shown as figure 11, the first series of comparisons will be applied between VE-based dynamic analysis and mockup-based dynamic analysis. VE-based dynamic analysis refers to the analysis procedure that using JRCM to analyze movements of DHM driven by subject motions captured in VE environment. And mockup-based dynamic analysis refers to the analysis procedure that using JRCM to analyze movements of DHM driven by subject motions captured in mockup environment. The calculated risks will be compared firstly to test the validity and reliability, and detailed comparisons among information that is input into the JRCM will be checked in order to figure out problems.

4.1.1 Comparison of Risks

Risks of the motions performed by DHM are calculated, by using movements of each subject for some tasks. And risks data corresponding to mockup-based motions and those corresponding to VE-based motions will be compared.

Mean values will be compared firstly.

Mean Value

Table 6 shows the mean risk value of all subjects for each trial of three different kinds of tasks. "Mockup" and "VE" refer to two kinds of environments where the human movements used to drive the human manikin are achieved; "FL0" refers to front lift with 0 pound load, "FL20" refers to front lift with 20 pounds load, and "SL" refers to side lift with 1 pound load. It will be the same at the following sections to use these terms.

Table 6

Comparison of General Mean Risk Value across Subjects

Risk	Mockup	VE
FL0	0.89772	0.842651
FL20	0.794317	0.824552
SL	0.455116	0.525607

From the table, we can find out several points.:

Firstly, the task of side lifting brings most risks for subjects, and although front lifting with 20 pounds brings more risks than front lifting with 0 pound, it is not a big different. This may be caused that a load of 20 pounds is not very heavy for adult. This trend can be supported with both mockup-based and VE-based analysis.

Secondly, for tasks of FL20 and SL, VE-based analysis offers smaller value, which means higher risk. So it seems that when subjects are doing those two tasks in VE, they perform some more dangerous motions. While for FL0 task, the result is opposite.

Paired t-test

Although both kinds of analysis offer different risks value, we are hoping that they represent same trend; and beyond the internal error caused by limitation of VE, two methods can offer similar analysis results. In order to do that, calculated risk for same task for each subject will be compared. Since mean values of two methods are different from each other, and directly applied paired t-test shows that output from two methods are not equal. In that case, we need to prove if the difference can be fixed. In order to deal with that, following steps will be implemented:

1. Calculate the difference between mean outputs of two methods for each task using data of trial two;

2. Since the most difference between output of these two methods is generated from the limitation of VE, so for specified task, difference between two methods in every trials should be similar;

3. Using the difference calculated from data of trial two to fix the results of VE-based dynamic analysis of trial one; and we will assume that fixed VE-based dynamic analysis outputs should be equal to mockup-based dynamic analysis outputs. If so, we can always use data of one trial to fix the results of other trials in order to make VE-based dynamic analysis to offer similar risk predictions as mockup-based analysis; in other words, the difference can be fixed.

For FL0 task, in data of trial two, mean risk value for mockup-based analysis is 0.91332, mean risk value for VE-based analysis is 0.85498, and so the difference is 0.05834. In data of trial one, add 0.05834 to all output risk values of VE-based analysis to achieve fixed VE-based outputs with mean μ_2; and suppose mean value of mockup-based analysis is μ_1. Paired t-test is used to test the following hypothesis:

$$H0: \mu_1 - \mu_2 = 0$$

$$H1: \mu_1 - \mu_2 \neq 0$$

The result is:

t Stat	-0.23683
P(T<=t) two-tail	0.81416
t Critical two-tail	2.030108

We can not reject H0. So for the task of front lifting with 0 pound, fixed VE-based analysis offers risks value same as those offers by mockup-based analysis.

For FL20 task, in data of trial two, mean risk value for mockup-based analysis is 0.79151, mean risk value for VE-based analysis is 0.84372, and so the difference is -0.05221. In data of trial one, add -0.05221to all output risk values of VE-based analysis to achieve fixed VE-based outputs with mean μ_2; and suppose mean value of mockup-based analysis is μ_1. Paired t-test is used to test the following hypothesis:

$$H0: \mu_1 - \mu_2 = 0$$

$$H1: \mu_1 - \mu_2 \neq 0$$

The result is:

t Stat	0.99779
P(T<=t) two-tail	0.32523
t Critical two-tail	2.030108

We can not reject H0. So for the task of front lifting with 20 pound, fixed VE-based analysis offers risks value same as those offers by mockup-based analysis.

For SL task, in data of trial two, mean risk value for mockup-based analysis is 0.51327, mean risk value for VE-based analysis is 0.71501, and so the difference is -0.20174. In data of trial one, add -0.20174 to all output risk values of VE-based analysis to achieve fixed VE-based outputs with mean μ_2; and suppose mean value of mockup-based analysis is μ_1. Paired t-test is used to test the following hypothesis:

$$H0: \mu_1 - \mu_2 = 0$$

$$H1: \mu_1 - \mu_2 \neq 0$$

The result is:

t Stat	1.84864
P(T<=t) two-tail	0.07377
t Critical two-tail	2.030108

We can not reject H0. So for the task of side lifting with 1 pound, VE-based analysis offers risks value same as those offers by mockup-based analysis.

To sum up, although mockup-based analysis and VE-based analysis offer different risk values, their outputs are in same trends. And after fix using data of other trials, fixed VE-based analysis can offer similar results as mockup-based analysis.

Two-factor ANOVA Test

In this experiment, mockup-based analysis and VE-based analysis are used to analyze motions of three tasks (FL0, FL20 and SL) performed by 36 subjects. A two-factor ANOVA test is applied to check the influence from two factors, analysis methods and tasks, to affect risk value. The model will be used is

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk} \quad \begin{cases} i = 1,2 \\ j = 1,2,3 \\ k = 1,2,\ldots,36 \end{cases}$$

Here, τ is the effect of two analysis methods, β is the effect of three tasks, and $\tau\beta$ is the effect of the interaction between those two.

Following hypotheses will be tested.

1. $H0: \tau_1 = \tau_2 = 0$
   $H1:$ at least one $\tau_i \neq 0$
2. $H0: \beta_1 = \beta_2 = \beta_3 = 0$
   $H1:$ at least one $\beta_i \neq 0$
3. $H0: (\tau\beta)_{11} = (\tau\beta)_{12} = \cdots = (\tau\beta)_{23} = 0$
   $H1:$ at least one $(\tau\beta)_{ij} \neq 0$

The result is shown as following.

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Methods	0.012507	1	0.012507	0.503798	0.478623	3.886121
Tasks	5.994342	2	2.997171	120.7274	1.25E-35	3.038877
Interaction	0.147976	2	0.073988	2.980264	0.052932	3.038877
Within	5.213448	210	0.024826			
Total	11.36827	215				

For interaction, since P-value =0.052932 > 0.05, so can not reject H0, which means the interaction does not significantly affect risks value.

For different tasks, since P-value = 1.25E-35 < 0.05, so can reject H0, which means that different tasks do significantly affect the risks value calculated.

For different methods, since P-value = 0.478623 > 0.05, so can not reject H0, which means that using mockup-based analysis or VE-based analysis does not influence the risks value calculated.

From this ANOVA test, we can figure out that:

1. When subjects are doing different tasks, the risk values are significantly different from each others;
2. This test can support the conclusion that VE-based analysis does not offer very different risk values from those offered by mockup-based analysis.

4.1.2 Comparisons of Related Factors

As described in previous section, VE-based analysis and mockup-based analysis can offer risk values in same trend, and they are not significantly different. Since the output risk values are similar, it proves the validity of DVID environment in some sense. However, there are still some difference exists, and so in this section, detailed information used in JRCM will be analyzed to find out the problems.

Following table 7 shows mean values of all four kinds of calculated information across all subjects for three different kinds of tasks.

Table 7

Mean Values of Input Information for JRCM

MM(N×M)	Mockup	VE		MSF(º)	Mockup	VE
FL0	0	0		FL0	11.34517	33.55092
FL20	6.481971	5.917365		FL20	20.04339	31.67528
SL	0.31745	0.298109		SL	11.67304	31.73709
ATV(º/s)	Mockup	VE		MLV(º/s)	Mockup	VE
FL0	3.920831	2.64507		FL0	7.603095	10.24424
FL20	6.891211	2.577819		FL20	15.10792	11.25434
SL	29.4983	20.24312		SL	32.71373	12.79685

By examining the dynamic information calculated from different tasks, the different characteristics of motions in different environments can be addressed as followed.

For MM (most moment) which is calculated by multiplying load weight with distance of load from trunk. The results show that motions in mockup and VE are quite similar with respect MM, which tells that the most extension of hand in both environments is similar. So the MM factor does not significantly affect the final risk values to be different between two methods.

For MSF (maximum sagittal flexion), we can find out that subjects will perform much more sagittal flexion in VE for all tasks, rather than acting in mockup. This means that when doing tasks in VE, subjects will bend themselves much more than common cases, which is caused by limited view and unfamiliar interaction methods in VE. This situation will increase the risk for motions performed in VE.

For ATV (average twisting velocity), we can find out that motions in mockup have quicker velocity than those in VE. ATV serves to represent the acting speed, and so this can be explained that since VE is not exactly same as mockup, subjects would be tending to act slowly in most cases. Slow action will make movements in VE less dangerous.

For MLV (maximum lateral velocity), we can find out that in FL0 task, motions in mockup have slower velocity, while in other two tasks, motions in mockup have quicker velocity. MLV servers to represent the unreliable actions of subjects when doing tasks. Motions of FL0 task in mockup have slower MLV means subjects can perform stable lift action dealing with a small load. While when the task changes to be complex, unstable actions strongly increased, and MLV in mockup increases, too. Higher MLV means higher risk values.

When the tasks, especially the load weight changes, corresponding flexion and velocity greatly changes for motions in mockup, this is caused by the increase of complex and difficulty to perform such tasks; however, for VE, the flexion and velocity do not change significantly (except for ATV in SL task, which is a special case). This situation is caused by the insufficiency of VE to offer subjects feeling of load, better view and proper interacting methods.

To sum up, the different risk values between mockup-based analysis and VE-based analysis are mostly generated by: firstly, much slower acting speed for subjects in VE; and secondly, disability to change flexion and velocity for subjects in VE when doing different tasks with various load weight

.

4.1.3 Comparison via Two Trials

In this section, paired t-test is applied to test output risk values of each method for each task. By examining this, we can figure out that if the two trials can have same output risk values. Comparison will be applied based on $\alpha = 0.05$, and difference between two trials = 0.

FL0

	Mockup-based Analysis	VE-based Analysis
Hypothesis	H0: There are same risk values for two trials. R1 = R2 H1: R1 ≠ R2	H0: There are same risk values for two trials. R1 = R2 H1: R1 ≠ R2
Test results	t Stat: -0.8237 P(T<=t): 0.4230 t Critical: 2.1314	t Stat: 0.6272 P(T<=t): 0.5400 t Critical: 2.1314
Conclusion	Can not reject H0.	Can not reject H0.

For the task of FL0, both mockup-based analysis and VE-based analysis offer very good reliability for their output results.

FL20

	Mockup-based Analysis	VE-based Analysis
Hypothesis	H0: There are same risk values for two trials. R1 = R2 H1: R1 ≠ R2	H0: There are same risk values for two trials. R1 = R2 H1: R1 ≠ R2
Test results	t Stat: 1.7221 P(T<=t): 0.1056 t Critical: 2.1314	t Stat: 1.0047 P(T<=t): 0.3310 t Critical: 2.1314
Conclusion	Can not reject H0.	Can not reject H0.

For the task of FL20, both mockup-based analysis and VE-based analysis offer good reliability for their output risk values. But the test results show that the reliability is not as good as that for FL0 task. This may be caused by the load weight increase, which makes subjects to be harder to keep same actions when doing different trials. And we can find out that for mockup-based analysis, there is one subject which has quite different motions for both trials. If analyzing without that subject, we can get the results like: t Stat = 1.3132, P (T<=t) = 0.2102 and t Critical = 2.1448.

SL

	Mockup-based Analysis	VE-based Analysis
Hypothesis	H0: There are same risk values for two trials. R1 = R2 H1: R1 ≠ R2	H0: There are same risk values for two trials. R1 = R2 H1: R1 ≠ R2
Test results	t Stat 2.5366 P(T<=t) 0.0228 t Critical 2.1314	t Stat -1.4429 P(T<=t) 0.1696 t Critical 2.1314
Conclusion	Reject H0.	Can not reject H0.

For the task of SL, mockup-based analysis output is not reliable since risk values from two trials are significantly different; however, the VE-based analysis outputs reliable risk values since risks of both trials are similar enough. In order to figure out the reason for above situation, detailed dynamic information will be analyzed. Table 8 shows the mean values of required dynamic information for all.

Table 8

Mean Values of Required Dynamic Information for Both Analysis Methods (SL task)

Methods	Trial	MM	MSF	ATV	MLV
Mockup-based	1	0.321645	10.84615	23.58014	28.694
	2	0.322729	9.524345	26.07621	31.30223
VE-based	1	0.299192	32.24317	19.92295	12.79685
	2	0.30402	32.93742	12.8422	14.24808

No obvious problems can be found by examining mean values to decide why mock-up based outputs are not reliable. So paired t-test will be applied and shown as Table 9.

Table 9

Results of Two-tails Paired T-test for Dynamic Information between Two Trials

Methods	MM		MSF	
Mockup-based	t Stat	-0.5894	t Stat	0.7902
	P(T<=t)	0.2824	P(T<=t)	0.4417
	t Critical	2.1314	t Critical	2.1314
	ATV		MLV	
	t Stat	-2.1645	t Stat	-9.1826
	P(T<=t)	0.0470	P(T<=t)	1.5158E-07
	t Critical	2.1314	t Critical	2.1314
VE-based	MM		MSF	
	t Stat	-0.5484	t Stat	-0.5483
	P(T<=t)	0.5915	P(T<=t)	0.5915
	t Critical	2.1314	t Critical	2.1314
	ATV		MLV	
	t Stat	1.6926	t Stat	-1.5026
	P(T<=t)	0.1112	P(T<=t)	0.1537
	t Critical	2.1314	t Critical	2.1314

From these series of paired t-test, we can address the following two findings:

1. For mockup-based analysis and VE-based analysis of SL task, the values of factors MM and MSF are close enough between two trials, across all subjects; and thus, these two factors will not influence the reliability of final output risk values.

2. For mockup-based analysis of SL task, the values of ATV and MLV are not close to each other between two trials; however, for VE-based analysis, they are close enough, although not

as good as values of another two factors, MM and MSF. From here, we can figure out the reason to make mockup-based analysis of SL task generate unreliable outputs is that subjects perform different twisting and lateral velocity when doing two trials of side lifting tasks.

To sum up, output risk values of both mockup-based analysis method and VE-based analysis method are reliable, which is represented as the similar value between two trials. While the only exception is risk values of SL task calculated using mockup-based analysis method. The reason for that is different velocity of subjects' movements when side lifting loads twice.

4.2 DHM-based Analysis vs. MOCAP-based Analysis Results

In previous section, comparisons have been made between mockup-based and VE-based analysis. Although these comparisons can represent influence on output risk values from the difference between VE and mockup, errors caused by Jack software can not be checked, since all those two methods are based on movements of DHM. In this section, motions of real subjects are imported into JRCM to calculate corresponding risk values, which can be called MOCAP-based analysis. Since motions captured directly from subjects performing tasks in mockup are accurate, JRCM output risks based on these kinds of motions can be regarded as standard to test Jack errors. Comparison will be applied among MOCAP-based analysis, mockup-based analysis and VE-based analysis.

4.2.1 Comparison of Risks

Firstly, output risk values will be used as comparing targets. Risk values calculated based on captured subject-motions in mockup, motions of DHM driven by mockup-based-movement and motions of DHM driven by VE-based-movement.

Mean Value

Table 10

Comparison of General Mean Risk Value across Subjects

Risk	Mockup	VE	MOCAP
FL0	0.89772	0.842651	0.92183
FL20	0.794317	0.824552	0.85844
SL	0.455116	0.525607	0.57794

Table 10 shows all the mean risk values calculated using three analyses for three tasks, and these values are averaged across all subjects. Here MOCAP refers to MOCAP-based analysis. We can find out following points from that table:

1. MOCAP-based analysis offers highest risk values for all three tasks, which means that directly captured motions from subjects in mockup have fewest risks compare to movements of DHM.
2. Same as the other two analysis output, MOCAP-based analysis also shows the trend that FL0 have largest risk values, FL20 have similar values, and SL have much smaller values. This situation means that SL is most dangerous, FL20 has less risk and FL0 is safest.

Paired T-test

Although mean values show same trends for all three analysis methods, they are not same. In previous section, we have proved that although there is difference between outputs of mockup-based analysis and those of VE-based analysis, it can be fixed. In this section, comparison will be made between MOCAP-based and mockup-based analysis to check the errors of Jack, and also be made between MOCAP-based and VE-based analysis to validate the integration system.

For FL0 task, in data of trial two, mean risk value for mockup-based analysis is 0.91332, mean risk value for MOCAP-based analysis is 0.92121, and so the difference is 0.007892. In data of trial one, add 0.007892 to all output risk values of mockup-based analysis to achieve fixed mockup-based outputs with mean μ_2; and suppose mean value of MOCAP-based analysis is μ_1. Paired t-test is used to test the following hypothesis:

$$H0: \mu_1 - \mu_2 = 0$$

$$H1: \mu_1 - \mu_2 \neq 0$$

The result is:

t Stat	2.77734
P(T<=t) two-tail	0.008747
t Critical two-tail	2.030107

We can reject H0. So for the task of front lifting with 0 pound, MOCAP-based analysis offers risk values are still significantly different from fixed mockup-based analysis.

For FL20 task, in data of trial two, mean risk value for mockup-based analysis is 0.79151, mean risk value for MOCAP-based analysis is 0.84182, and so the difference is 0.0503. In data of trial one, add 0.0503 to all output risk values of mockup-based analysis to achieve fixed mockup-based outputs with mean μ_2; and suppose mean value of MOCAP-based analysis is μ_1. Paired t-test is used to test the following hypothesis:

$$H0: \mu_1 - \mu_2 = 0$$

$$H1: \mu_1 - \mu_2 \neq 0$$

The result is:

t Stat	0.99215
P(T<=t) two-tail	0.32793
t Critical two-tail	2.030108

We can not reject H0. So for the task of front lifting with 20 pound, MOCAP-based analysis offers risk values same as those offers by fixed mockup-based analysis.

For SL task, in data of trial two, mean risk value for mockup-based analysis is 0.51327, mean risk value for MOCAP-based analysis is 0.56506, and so the difference is 0.05179. In data of trial one, add 0.05179 to all output risk values of mockup-based analysis to achieve fixed mockup-based outputs with mean μ_2; and suppose mean value of MOCAP-based analysis is μ_1. Paired t-test is used to test the following hypothesis:

$$H0: \mu_1 - \mu_2 = 0$$

$$H1: \mu_1 - \mu_2 \neq 0$$

The result is:

t Stat	2.43361
P(T<=t) two-tail	0.02019
t Critical two-tail	2.030108

We can reject H0. So for the task of side lifting with 1 pound, MOCAP-based analysis offers risk values are still significantly different from fixed mockup-based analysis.

To sum up, even after fixing mockup-based analysis, we still get significant difference between outputs of these two analyses methods. This means that errors from Jack are significantly in this experiment, and can not be explained clearly. However, although in FL0 and SL tasks where H0 is rejected, we can still find that the "t Stat" values are not far away from "t critical two-tail" values, and we can not reject H0 in the task of FL20; these results mean that since MOCAP-based analysis and mockup-based analysis here are using same sources of motions, their analysis results are in same trend in some sense.

ANOVA Test

MOCAP-based analysis, mockup-based analysis and VE-based analysis are used to analyze motions of three tasks (FL0, FL20 and SL) performed by 36 subjects. A 3*3 ANOVA test is applied to check the influence from two factors, analysis methods and tasks, to affect risk value. The model will be used is

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk} \quad \begin{cases} i = 1,2,3 \\ j = 1,2,3 \\ k = 1,2,\ldots,36 \end{cases}$$

Here, τ is the effect of two analysis methods, β is the effect of three tasks, and $\tau\beta$ is the effect of the interaction between those two.

Following hypotheses will be tested.

1. $H0: \tau_1 = \tau_2 = \tau_3 = 0$
   $H1:$ at least one $\tau_i \neq 0$
2. $H0: \beta_1 = \beta_2 = \beta_3 = 0$
   $H1:$ at least one $\beta_i \neq 0$
3. $H0: (\tau\beta)_{11} = (\tau\beta)_{12} = \cdots = (\tau\beta)_{23} = 0$
   $H1:$ at least one $(\tau\beta)_{ij} \neq 0$

The result is shown as following:

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Sample	0.295952	2	0.147976	7.434533	0.0007	3.024404
Columns	8.38352	2	4.19176	210.6005	8.55E-59	3.024404
Interaction	0.170265	4	0.042566	2.138594	0.075895	2.400311
Within	6.269712	315	0.019904			
Total	15.11945	323				

From the results, we can figure out that although the interaction of three factors does not significantly influence the risk values, both different tasks and different methods can significantly affect the risk values. Comparing to previous ANOVA test about the mockup-based analysis and VE-based analysis, we can find that MOCAP-based analysis may offer significantly different risk values from the other two.

ANOVA test between MOCAP-based analysis and any of the other two methods approve above statement. Results are shown as following.

ANOVA test for MOCAP-based analysis and VE-based analysis						
Source of Variation	SS	df	MS	F	P-value	F crit
Sample	0.164146	1	0.164146	7.621152	0.006279	3.886121
Columns	4.67535	2	2.337675	108.536	4.27E-33	3.038877
Interaction	0.018665	2	0.009333	0.4333	0.648944	3.038877
Within	4.52303	210	0.021538			
Total	9.381191	215				
ANOVA test for MOCAP-based analysis and mockup-based analysis						
Source of Variation	SS	df	MS	F	P-value	F crit
Sample	0.267274	1	0.267274	20.02449	1.25E-05	3.886121
Columns	6.18248	2	3.09124	231.5994	7.55E-54	3.038877
Interaction	0.088757	2	0.044378	3.324878	0.03788	3.038877
Within	2.802945	210	0.013347			
Total	9.341456	215				

4.2.2 Comparison for Related Factors

In order to check why MOCAP-based analysis offers quite different risk values from the other two, dynamic information required for JRCM will be analyzed. Following table 11 shows mean values of all four kinds of calculated information across all subjects for three different kinds of tasks.

Table 11

Mean values of input information for JRCM

MM(N×M)	Mockup	VE	MOCAP
FL0	0	0	0
FL20	6.481971	5.917365	6.8989
SL	0.31745	0.298109	0.333812
ATV(º/s)	Mockup	VE	
FL0	3.920831	2.64507	3.810508
FL20	6.891211	2.577819	6.850072
SL	29.4983	20.24312	25.27418
MSF(º)	Mockup	VE	
FL0	11.34517	33.55092	5.515908
FL20	20.04339	31.67528	7.268407
SL	11.67304	31.73709	2.039138
MLV(º/s)	Mockup	VE	
FL0	7.603095	10.24424	3.799682
FL20	15.10792	11.25434	8.916709
SL	32.71373	12.79685	26.4258

From above table, we can find out that only for MM factor, MOCAP-based analysis has similar input values with the other two methods; however, for other factors, MOCAP-based analysis has quite different input values.

4.3 Dynamic Analysis vs. Static Analysis

4.3.1 Mean Value Comparison

In this part, I will compare VE-based analysis with several static analysis tools including SSP, NIOSH and RULA. Those static analyses are also based on the postures of DHM, and have been proved to be valid. Comparisons in this section will help to check the validity of VE-based analysis method.

Table 12

Mean Risk Values

	JRCM	SSP	NIOSH
Front Lift (0 lb)	0.84265	203.89	0.0408
Front Lift (20 lb)	0.82455	212.69	0.8440
Side Lift (1 lb)	0.52560	196.19	0.0412

The purpose of using VID is to evaluate risk of different tasks, which is best represented by mean risk value of one task calculated across all subjects. Table 12 shows the mean risk values based on different ergonomics tools.

In the table, JRCM is calculated using the above formula. SSP is FLEX/EXT Moment for final Posture and NIOSH is calculated using the following equation:

LI (Lifting Index) = Load Weight / RWL

From the table, we can figure out that for the three different lift tasks, JRCM gives a clear discrimination of the risk of them: Side Lift > Front Lift with 20lb > Front Lift with 0lb. From SSP and NIOSH analysis, we can also draw the conclusion that Front Lift with 20lb has higher risk rather than Front Lift with 0lb clearly. But for Side Lift, SSP and NIOSH give a similar value as 0lb front lift, which shows that NIOSH is lack of enough consideration of rotations in transverse plane, and more SSP attributes are needed in order to analyze actions with much rotation. On the other hand, JRCM has quite round consideration of movement in all planes.

4.3.2 RULA vs. JRCM

RULA and JRCM were used to evaluate reach actions for all subjects. RULA can output Grand Score from 1 to 7 representing the risk value. In order to compare RULA and JRCM output, JRCM output was firstly indexed, and then JRCM output was categorized based on corresponding RULA Grand Score. For example, JRCM output for reach action of subject 3 is 0.28975, which is the 10th if all the JRCM output is sorted from smallest to the highest, so its JRCM index is 10; higher index means higher risk. Since the RULA output for subject 3 is 7, so for the category whose RULA equal to 7, there is a JRCM index which is 10. Table 13 shows all the categories.

Table 13

JRCM Index Categorized by RULA

RULA	JRCM Index	Average
3	2, 4, 5, 6, 7, 8, 9, 13, 14, 17	8.5
4	3, 19	11
5	11	11
6	1, 12, 15	9.33(13)
7	10, 16, 18 20	16

Firstly, we can figure out that with the increase of RULA Grand Score, generally the JRCM index is increased. While since the JRCM analysis is influenced by maximum velocity in some planes, so it may have some abnormal points, like subject 18 whose RULA output is 6 while JRCM index is 1. If we remove this abnormal point, the average JRCM index is increased with the increase of RULA for all the subjects.

To sum up, we can say that JRCM based on motions captured based on mockup can discriminate risk level of tasks clearly; and based on the comparison with RULA, its analyses result is valid.

CHAPTER V

CONCLUSION

5.1 Validity of DVID

Validity of DVID is examined through three kinds of comparisons. In each comparison, there are some standards that can be used to test the highest integrated analysis method, VE-based dynamic analysis. VE-based dynamic analysis refers to the analysis procedure that using JRCM to analyze movements of DHM driven by subject motions captured in VE environment. And mockup-based dynamic analysis refers to the analysis procedure that using JRCM to analyze movements of DHM driven by subject motions captured in mockup environment. Mockup-based dynamic analysis method is also one of the DVID analysis methods.

5.1.1 Comparison between VE-based and Mockup-based Dynamic Analysis

This part directly compares two main analysis methods of DVID environment. In order to validate VE-based dynamic analysis, mockup-based dynamic analysis is regarded as stand, since mockup-based motions are more reliable and valid than VE-based ones.

By examining the mean risk values of two methods for all tasks, we should reject first null hypothesis which is that difference between mean dynamic ergonomics analysis results of both mockup-based dynamic analysis method and VE-based dynamic analysis method for each task should be equal to 0. But although there is difference between the estimations of both methods, they can predict risks for tasks in same trends, which mean they can all classify higher or lower risk tasks.

By applying paired t-test for fixed VE-based dynamic analysis and mockup-based dynamic analysis, we can not reject the second null hypothesis which is that difference between dynamic ergonomics analysis results of both mockup-based dynamic analysis method and VE-based dynamic analysis method for each subject to perform each task should be equal to 0 or can be fixed. Since after fixing, both methods can offer same prediction of risks for tasks. This means that after fixing process, VE-based analysis can be used to replace mockup-based analysis.

And ANOVA test tells us change of these two analysis methods can not significantly influence the risk values, which means that these two methods generally offer same risk predictions.

The reason for difference between analysis results of these two methods can be studied by examination of detailed dynamic information used for two methods. We find out that limitation of VE and unstable velocity are the main reason to generate those differences.

5.1.2 Comparison between DHM-based and MOCAP-based Dynamic Analysis

In this part, MOCAP-based dynamic analysis means the procedure to use JRCM to calculate risk values for motions of subjects that were directly captured in mockup. Since these motions are very reliable, MOCAP-based analysis results are regarded as standard to validate both VE-based and mockup-based analysis methods. The later two methods are all based on movements of DHM.

By examining the mean values for each task, we should reject the first null hypothesis which is that difference between mean outputs of DHM-based dynamic ergonomics analysis and mean outputs of MOCAP-based dynamic ergonomics analysis for each task should be equal to 0. However, although difference exists, we can find out that three analysis methods offer similar trends of risks for those tasks, and the risk values are close.

But by doing paired t-test for fixed mockup-based analysis and MOCAP analysis, we should also reject the second null hypothesis which is that difference between dynamic ergonomics analysis results of both DHM-based dynamic analysis method and MOCAP-based dynamic analysis method for each subject to perform each task should be equal to 0 or can be fixed. So we can not say that the significant difference between outputs of these two methods can be fixed. This difference is mainly caused by errors within Jack software.

After checking the detailed dynamic information used in all three methods, directly captured motions of subjects are much more stable and easy, with much smaller flexion and slower velocity comparing the other two.

5.1.3 Comparison between Dynamic Analysis and Static Analysis

In this part, static analysis tools like SSP, NIOSH and RULA are used as standard to validate VE-based dynamic analysis method. By examining the mean values for three tasks and categorizing JRCM index with RULA outputs, we can draw the conclusion that VE-based dynamic analysis method can predict similar risk trends as those static tools, and the dynamic method can give more round consideration when doing analysis. So we can not reject the hypothesis which is that VE-based dynamic analysis outputs are representing similar risk information (mean risk value) for each task as static analysis outputs.

5.2 Reliability of DVID

Reliability of DVID environment is tested by checking the reliability of VE-based dynamic analysis method and mockup-based method. Paired t-test is implemented to check the output risk values for two trials of each task. The results show that for VE-based dynamic analysis method, the output risk values are reliable for all three tasks. So we can not reject the first hypothesis which is that difference between two-trials of VE-based dynamic ergonomics analysis results for each subject for each task is 0. However, for mockup-based method, the output risk value is not reliable for SL task. So we can reject the second hypothesis which is that difference between two-trials of mockup-based dynamic ergonomics analysis results for each subject for each task is 0. But since for the other two tasks, mockup-based method offers reliable outputs, and even for SL task the difference between two trials are not so large, so generally we can say mockup-based method is reliable. Reason to cause that has been analyzed by examining dynamic information.

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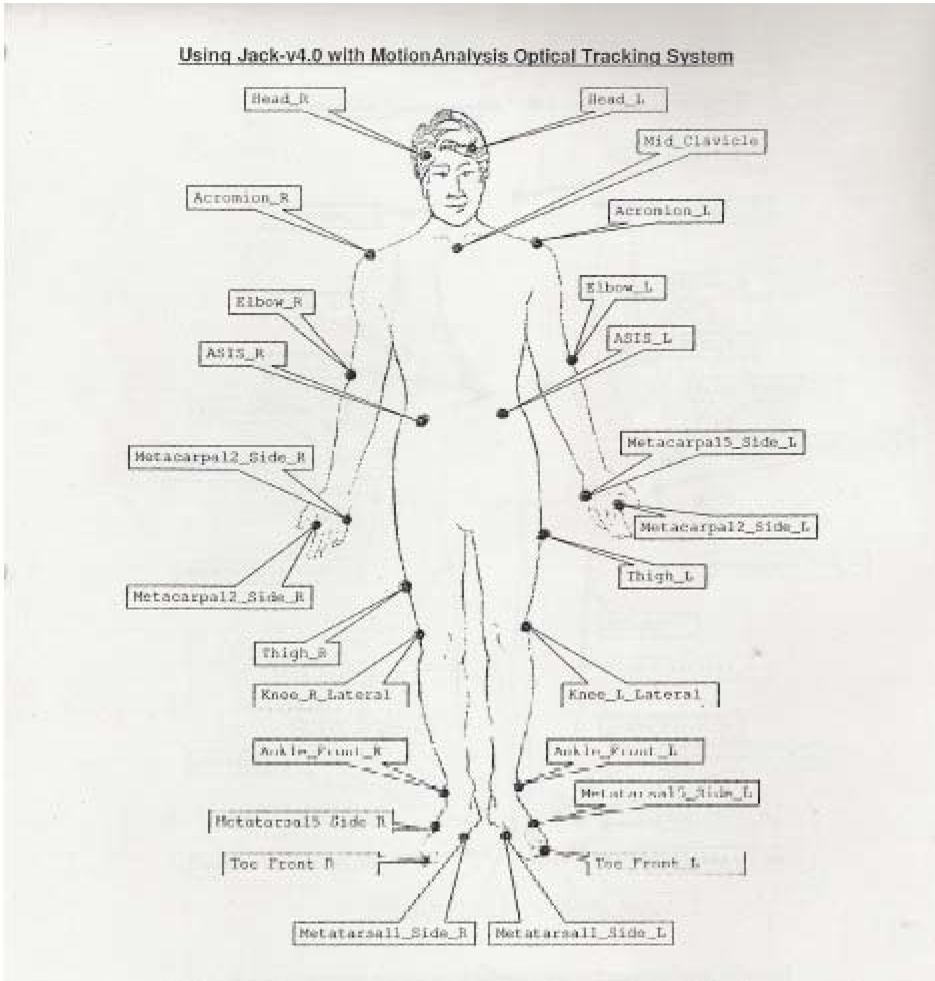
APPENDIX A

JACK MARKER SET PLACEMENT

A.1

Front View



A.2

Rear View

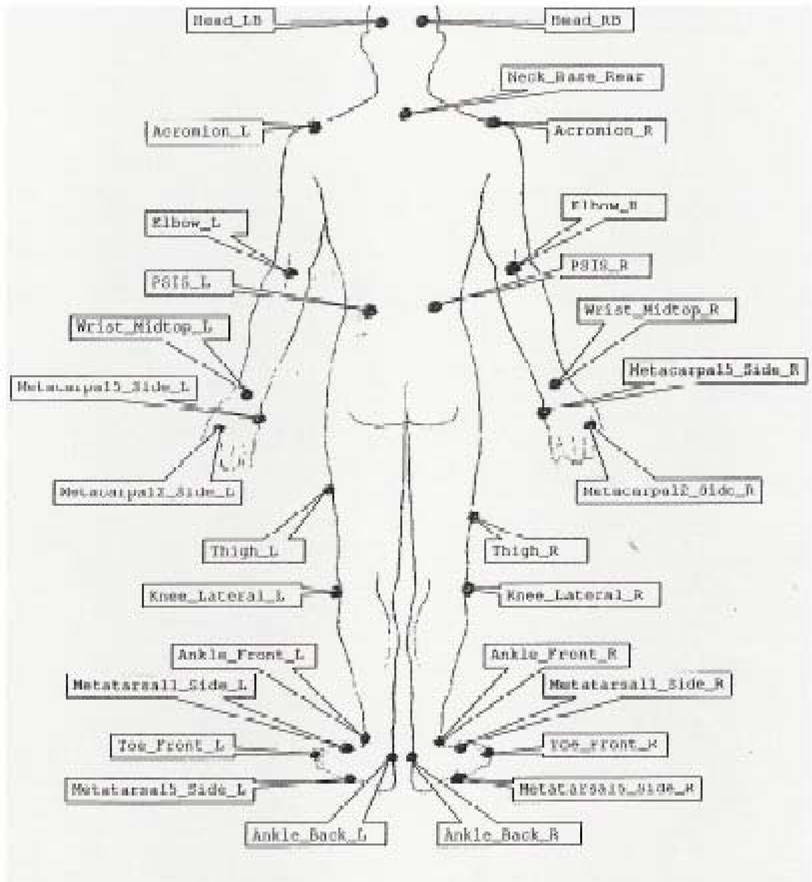


Figure 2. Markers for MotionAnalysis Optical Tracking System (Back)

A.3

Side View

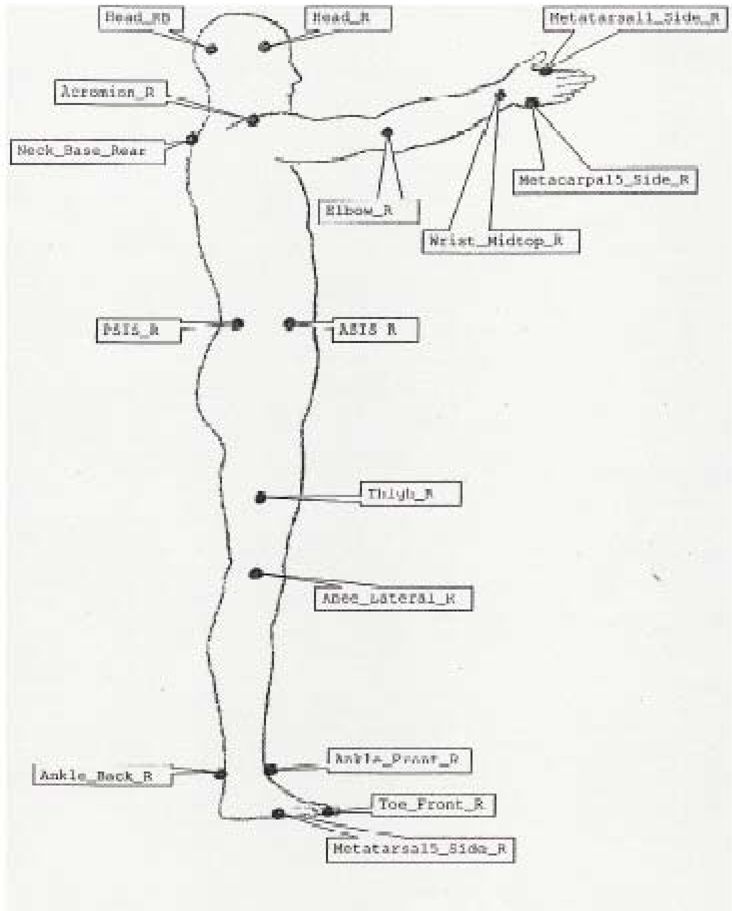


Figure 3. Markers for MotionAnalysis Optical Tracking System (Side)

APPENDIX B

SAMPLE DATA ANALYSIS PROCESS

B.1
Sample worksheet (FL0) of loading marker data for Jack manikin motion

PSIS_L			PSIS_R			Neck_Base_Rear		
8.844	103.7959	-9.4526	-3.2961	104.9632	-10.75	2.2877	138.6996	-6.9614
8.837	103.7758	-9.4027	-3.2932	104.9527	-10.7333	2.2805	138.701	-6.9515
8.8367	103.7706	-9.3891	-3.2741	104.9557	-10.7237	2.2866	138.692	-6.9303
8.8484	103.7784	-9.3894	-3.276	104.9548	-10.7152	2.2834	138.6957	-6.9308
8.8641	103.786	-9.3717	-3.2736	104.9357	-10.6809	2.276	138.69	-6.9344
8.8557	103.7732	-9.3437	-3.2856	104.9321	-10.674	2.2605	138.6772	-6.9294
8.834	103.773	-9.3424	-3.2856	104.9321	-10.674	2.2397	138.6727	-6.926
8.8315	103.7744	-9.3369	-3.2918	104.9409	-10.6748	2.2361	138.6763	-6.9245
8.8311	103.7711	-9.3275	-3.2856	104.9321	-10.674	2.2327	138.6806	-6.9274
8.8311	103.7711	-9.3275	-3.2856	104.9321	-10.674	2.218	138.6784	-6.9205
8.8311	103.7711	-9.3275	-3.2856	104.9321	-10.674	2.218	138.6784	-6.9205
8.8311	103.7711	-9.3275	-3.2913	104.9361	-10.6634	2.2239	138.672	-6.9211
8.8333	103.7627	-9.3151	-3.2975	104.945	-10.6642	2.2239	138.672	-6.9211
8.8152	103.7636	-9.311	-3.2936	104.9428	-10.6702	2.2094	138.6713	-6.9204
8.8152	103.7636	-9.311	-3.298	104.9411	-10.6538	2.2128	138.6668	-6.9175
8.8108	103.7726	-9.3109	-3.3014	104.9497	-10.6613	2.2094	138.6713	-6.9204
8.8108	103.7726	-9.3109	-3.3019	104.9458	-10.6506	2.2094	138.6713	-6.9204
8.8108	103.7726	-9.3109	-3.3082	104.9512	-10.6546	2.1999	138.6822	-6.9217
8.8071	103.7771	-9.3086	-3.3433	104.9621	-10.664	2.2006	138.6733	-6.915
8.7982	103.7723	-9.3166	-3.3605	104.9487	-10.6478	2.2018	138.6678	-6.9246
8.7676	103.7603	-9.3164	-3.3574	104.9406	-10.6406	2.1951	138.6763	-6.9297
8.7713	103.7558	-9.3186	-3.3718	104.9407	-10.6576	2.1971	138.6749	-6.933
8.7725	103.7576	-9.3272	-3.3914	104.9287	-10.6662	2.196	138.6772	-6.9382
8.773	103.7608	-9.3366	-3.3997	104.9056	-10.6499	2.2016	138.6717	-6.9408
8.773	103.7608	-9.3366	-3.3872	104.9208	-10.6631	2.186	138.6847	-6.9609
8.7719	103.7661	-9.3456	-3.4221	104.9288	-10.6757	2.186	138.6847	-6.9609
8.773	103.7608	-9.3366	-3.4026	104.9311	-10.6847	2.1871	138.669	-6.975
8.7667	103.75	-9.3536	-3.4129	104.9145	-10.6893	2.1877	138.6736	-6.989
8.7674	103.7528	-9.3563	-3.417	104.8989	-10.6919	2.1861	138.6775	-7.0027
8.76	103.7531	-9.3708	-3.4194	104.896	-10.7149	2.1891	138.675	-7.0062
8.7424	103.7538	-9.3764	-3.3842	104.9061	-10.7413	2.1891	138.675	-7.0062
8.7325	103.7503	-9.4032	-3.4058	104.9044	-10.7636	2.1861	138.6775	-7.0027
8.7363	103.7514	-9.4195	-3.4073	104.9159	-10.7839	2.1802	138.6816	-6.988
8.7363	103.7514	-9.4195	-3.4089	104.923	-10.7939	2.1719	138.6954	-6.9858
8.7363	103.7553	-9.4291	-3.4047	104.9404	-10.8	2.1797	138.7035	-6.9693
8.724	103.7595	-9.4337	-3.4119	104.931	-10.8015	2.1797	138.7035	-6.9693
8.7203	103.7691	-9.4331	-3.4119	104.931	-10.8015	2.1747	138.6962	-6.9618
8.7239	103.7664	-9.4499	-3.3963	104.927	-10.8172	2.1797	138.7035	-6.9693
8.7239	103.7664	-9.4499	-3.3963	104.927	-10.8172	2.1797	138.7035	-6.9693
8.7249	103.7608	-9.4637	-3.3963	104.927	-10.8172	2.1786	138.7059	-6.9746
8.7455	103.7825	-9.4827	-3.4054	104.9201	-10.8305	2.1669	138.7023	-6.9918

8.7345	103.7817	-9.5026	-3.4327	104.9233	-10.8426	2.1655	138.7068	-7.0089
8.7297	103.7947	-9.517	-3.4358	104.9073	-10.8569	2.152	138.6996	-7.0256
8.7299	103.7871	-9.539	-3.4379	104.8996	-10.8612	2.1461	138.6955	-7.0353
8.7313	103.7936	-9.5594	-3.4516	104.912	-10.8961	2.1386	138.6992	-7.1052
8.7176	103.7906	-9.5663	-3.4272	104.9193	-10.9192	2.0991	138.687	-7.1166
8.7322	103.7774	-9.5722	-3.4135	104.9029	-10.9358	2.067	138.6887	-7.1279
8.7046	103.7684	-9.5882	-3.4082	104.9054	-10.9599	2.0672	138.698	-7.1522
8.6893	103.7504	-9.6039	-3.4118	104.9194	-10.9785	2.0705	138.6991	-7.1729
8.6919	103.7495	-9.6107	-3.4092	104.9187	-10.9862	2.0741	138.7034	-7.2135
8.6958	103.7479	-9.6208	-3.4092	104.9187	-10.9862	2.0913	138.712	-7.2441
8.7189	103.7637	-9.6448	-3.4186	104.9127	-10.992	2.082	138.7225	-7.2645
8.7241	103.7679	-9.6733	-3.4113	104.9168	-11.0155	2.0732	138.7114	-7.2776
8.7061	103.7655	-9.7285	-3.4232	104.913	-11.0255	2.075	138.7051	-7.3204
8.6939	103.754	-9.7361	-3.4222	104.9162	-11.0474	2.0628	138.7074	-7.361
8.6841	103.7475	-9.7816	-3.432	104.9116	-11.096	2.0645	138.7174	-7.4125
8.6724	103.7506	-9.81	-3.4366	104.9193	-11.0968	2.0831	138.7339	-7.4501
8.6727	103.7577	-9.8278	-3.4441	104.9417	-11.1209	2.0808	138.7375	-7.4545
8.704	103.7722	-9.8794	-3.4159	104.9453	-11.1538	2.0832	138.7357	-7.4587
8.6858	103.7843	-9.9298	-3.4276	104.9613	-11.1543	2.0793	138.7506	-7.4817
8.6573	103.7758	-9.9671	-3.4227	104.9659	-11.2345	2.1003	138.7514	-7.4914
8.6627	103.7757	-9.9857	-3.4054	104.9895	-11.2474	2.1219	138.7616	-7.5123
8.6939	103.817	-10.0481	-3.4112	104.9807	-11.2522	2.1212	138.7636	-7.5176
8.7217	103.85	-10.1437	-3.3882	105.0007	-11.2832	2.1387	138.7658	-7.5441
8.723	103.8912	-10.2333	-3.3748	105.0065	-11.2895	2.1378	138.7589	-7.5914
8.7065	103.9167	-10.2061	-3.3359	105.018	-11.3248	2.1411	138.7502	-7.6029
8.7335	103.9028	-10.2741	-3.313	105.0718	-11.4401	2.1832	138.7807	-7.5936
8.7528	103.9208	-10.3663	-3.3254	105.1045	-11.473	2.2047	138.7948	-7.5603
8.7959	103.9513	-10.4311	-3.3282	105.1292	-11.5215	2.216	138.8134	-7.5498
8.7923	103.9811	-10.4742	-3.2938	105.1863	-11.5974	2.2363	138.861	-7.5279
8.7959	104.0121	-10.5013	-3.2872	105.224	-11.6278	2.2417	138.8779	-7.5221
8.8557	104.0536	-10.592	-3.2708	105.2952	-11.7173	2.269	138.9076	-7.5196
8.8741	104.0575	-10.6261	-3.2521	105.3094	-11.7744	2.2574	138.9073	-7.524
8.8566	104.2174	-10.8335	-3.1965	105.3449	-11.854	2.2796	138.927	-7.5296
8.8821	104.1917	-10.8469	-3.1869	105.3908	-11.9195	2.2867	138.9334	-7.5294
8.8821	104.1917	-10.8469	-3.1869	105.3908	-11.9195	2.2867	138.9334	-7.5294
8.9389	104.2011	-10.8932	-3.1511	105.438	-12.0371	2.3029	138.9551	-7.5571
8.9924	104.2393	-10.9565	-3.1418	105.4527	-12.0867	2.3264	138.9801	-7.5818
8.983	104.2592	-10.9948	-3.0868	105.4871	-12.162	2.3301	138.9874	-7.6005
9.0448	104.3088	-11.0944	-3.0593	105.5542	-12.2667	2.3142	139.0071	-7.6202
9.0518	104.3323	-11.1509	-3.0301	105.5761	-12.3074	2.3185	139.0396	-7.6376
9.0789	104.3849	-11.2297	-3.0138	105.6036	-12.3823	2.3379	139.0419	-7.6456
9.1158	104.4677	-11.3438	-2.9387	105.6749	-12.5536	2.3275	139.082	-7.6506
9.1623	104.4995	-11.4261	-2.905	105.7132	-12.637	2.3044	139.1168	-7.6342
9.1931	104.5984	-11.4849	-2.888	105.7497	-12.697	2.2588	139.1327	-7.6208
9.2218	104.6384	-11.5853	-2.8483	105.8103	-12.8268	2.2411	139.1613	-7.5779

9.3075	104.7769	-11.7317	-2.8628	105.8868	-13.0054	2.1888	139.208	-7.5095
9.3075	104.7769	-11.7317	-2.8628	105.8868	-13.0054	2.1888	139.208	-7.5095
9.297	104.8453	-11.8391	-2.8549	105.9433	-13.0986	2.1608	139.2276	-7.4733
9.3291	105.0335	-12.0609	-2.8562	106.0834	-13.2868	2.105	139.3203	-7.3157
9.3228	105.0938	-12.1688	-2.8934	106.1848	-13.3966	2.0772	139.3507	-7.273
9.2507	105.233	-12.39	-2.845	106.3555	-13.5882	2.0062	139.4269	-7.0753
9.2937	105.3111	-12.5062	-2.9261	106.431	-13.6495	1.969	139.4342	-6.9631
9.2471	105.3879	-12.5858	-2.9224	106.5258	-13.7485	1.9407	139.4849	-6.8435
9.1809	105.5023	-12.7524	-2.9601	106.6611	-13.8357	1.8866	139.5615	-6.5834
9.2034	105.5992	-12.8332	-2.9563	106.7213	-13.8739	1.8388	139.5962	-6.441
9.1696	105.661	-12.9112	-2.9628	106.8342	-13.9382	1.8113	139.6185	-6.3108
9.1659	105.8098	-12.9915	-2.9455	106.9499	-13.9952	1.7333	139.6532	-5.9958
9.1556	105.8374	-13.0213	-2.973	106.9847	-14.0209	1.7048	139.6558	-5.8833
9.1556	105.8374	-13.0213	-2.973	106.9847	-14.0209	1.7048	139.6558	-5.8833
9.095	105.9064	-13.0867	-3.0142	107.0824	-14.0629	1.6639	139.6688	-5.6046
9.0755	105.984	-13.1105	-3.0256	107.1081	-14.07	1.6281	139.6829	-5.4928
9.0683	106.0321	-13.1393	-3.0553	107.1943	-14.0763	1.6282	139.6959	-5.2558
9.0613	106.0429	-13.1407	-3.06	107.2489	-14.0813	1.6331	139.7205	-5.149
9.0507	106.074	-13.1489	-3.0373	107.3173	-14.0541	1.6372	139.7405	-4.964
9.0571	106.0977	-13.1372	-3.0416	107.3204	-14.0459	1.5948	139.7381	-4.8877
9.0433	106.1272	-13.1161	-3.0191	107.331	-14.0387	1.6154	139.7402	-4.8131
9.035	106.1584	-13.1064	-3.0409	107.3572	-14.0091	1.6028	139.7435	-4.7749
9.0191	106.1596	-13.0983	-3.0571	107.3604	-14.0118	1.5897	139.7482	-4.6911
8.9942	106.1607	-13.0684	-3.0514	107.3712	-13.9768	1.5934	139.7458	-4.6535
9.0095	106.1618	-12.9943	-3.0699	107.4023	-13.9492	1.5847	139.7569	-4.592
9.0095	106.1618	-12.9943	-3.0699	107.4023	-13.9492	1.5847	139.7569	-4.592
9.0093	106.158	-12.9845	-3.0771	107.4146	-13.8909	1.584	139.76	-4.5747
9.0018	106.1637	-12.9653	-3.0963	107.3984	-13.8535	1.5643	139.772	-4.5671
8.9818	106.1498	-12.9375	-3.1138	107.3929	-13.8411	1.5517	139.7684	-4.563
8.9755	106.1444	-12.9211	-3.1306	107.3825	-13.7944	1.5569	139.7616	-4.5584
8.9372	106.1072	-12.8022	-3.1179	107.3486	-13.6948	1.5655	139.7717	-4.5717
8.9269	106.0969	-12.7865	-3.136	107.3429	-13.6587	1.565	139.7713	-4.5881
8.934	106.1003	-12.7673	-3.1386	107.3333	-13.6369	1.5815	139.772	-4.6057
8.9512	106.0757	-12.7132	-3.1463	107.3054	-13.5841	1.6057	139.7748	-4.6219
8.9454	106.0643	-12.6046	-3.1612	107.2809	-13.5032	1.6071	139.7624	-4.681
8.9554	106.0538	-12.5722	-3.1709	107.2381	-13.4518	1.6117	139.7716	-4.7065
8.9323	106.0547	-12.517	-3.1663	107.226	-13.3994	1.6421	139.7715	-4.7621
8.949	106.01	-12.4197	-3.1633	107.1788	-13.2891	1.6838	139.7676	-4.8394
8.949	106.01	-12.4197	-3.1633	107.1788	-13.2891	1.6838	139.7676	-4.8394
8.9661	105.9711	-12.366	-3.1641	107.1547	-13.262	1.6748	139.7648	-4.8569
8.9751	105.9366	-12.2715	-3.14	107.1016	-13.1542	1.7462	139.7723	-4.9658
8.9577	105.8909	-12.203	-3.1491	107.083	-13.1208	1.7561	139.7758	-5.033
8.9769	105.8313	-12.094	-3.1032	107.0371	-13.0137	1.8149	139.7408	-5.1096
9.0198	105.796	-12.013	-3.0801	106.999	-12.9551	1.8232	139.7473	-5.1742
9.0035	105.7525	-11.981	-3.0756	106.9518	-12.8891	1.8407	139.7525	-5.2379

9.0222	105.7036	-11.8409	-3.093	106.9041	-12.7656	1.8869	139.7318	-5.3344
9.0391	105.6808	-11.7859	-3.0941	106.8591	-12.7095	1.8947	139.7346	-5.389
9.0696	105.6076	-11.6342	-3.0441	106.7913	-12.6095	1.9464	139.7032	-5.4843
9.0881	105.5938	-11.6125	-3.0102	106.7572	-12.5487	1.9709	139.6944	-5.5533
9.0998	105.5676	-11.5419	-3.0085	106.7394	-12.4945	2.0134	139.6963	-5.6117
9.1067	105.5282	-11.4745	-3.0021	106.7275	-12.4622	2.0356	139.6646	-5.6339
9.1066	105.5318	-11.4384	-2.9968	106.6866	-12.3686	2.0446	139.6844	-5.6708
9.1152	105.4371	-11.3239	-2.9933	106.5922	-12.2818	2.0672	139.6357	-5.8031
9.1523	105.4139	-11.2739	-2.962	106.5509	-12.197	2.0741	139.622	-5.8279
9.1349	105.3426	-11.1641	-2.9851	106.5046	-12.1067	2.1452	139.6114	-5.9031
9.1474	105.3201	-11.0898	-3.0178	106.4704	-12.0774	2.1674	139.6049	-5.9464
9.1521	105.302	-11.0628	-2.9818	106.4187	-11.9986	2.1838	139.5888	-5.9868
9.1572	105.2645	-10.938	-2.9235	106.3867	-11.881	2.1986	139.568	-6.0394
9.1719	105.2108	-10.8883	-2.9079	106.3682	-11.8409	2.2404	139.5427	-6.0987
9.1947	105.1959	-10.8713	-2.976	106.3264	-11.7794	2.2417	139.5443	-6.1225
9.1764	105.1322	-10.7762	-2.9594	106.2792	-11.699	2.2332	139.5161	-6.1911
9.1764	105.1322	-10.7762	-2.9594	106.2792	-11.699	2.2332	139.5161	-6.1911
9.1512	105.0557	-10.7033	-2.9645	106.2063	-11.6218	2.2885	139.509	-6.2863
9.1417	105.0347	-10.6731	-2.9521	106.1878	-11.5614	2.2974	139.4904	-6.3284
9.1484	105.0071	-10.63	-2.953	106.1681	-11.5277	2.2772	139.4507	-6.3828
9.1782	104.9753	-10.5441	-2.9109	106.0777	-11.4411	2.2612	139.4298	-6.4838
9.1669	104.9348	-10.5022	-2.9042	106.0459	-11.3968	2.2938	139.4052	-6.5181
9.177	104.8624	-10.4065	-2.9223	105.987	-11.3262	2.2969	139.3755	-6.6213
9.1989	104.8321	-10.3677	-2.9121	105.9713	-11.2812	2.295	139.3554	-6.6855
9.1795	104.8029	-10.3282	-2.907	105.9378	-11.2339	2.3048	139.3452	-6.7388
9.1715	104.7514	-10.2543	-2.8827	105.8623	-11.1562	2.3166	139.3207	-6.8293
9.1711	104.7142	-10.2258	-2.8715	105.8352	-11.1361	2.3715	139.3189	-6.9264
9.1792	104.6908	-10.1977	-2.8735	105.836	-11.1276	2.3734	139.2979	-6.9487
9.1782	104.6822	-10.1735	-2.872	105.7974	-11.1185	2.3703	139.2692	-6.9852
9.1981	104.6794	-10.1475	-2.8626	105.7868	-11.1094	2.3641	139.2324	-7.0553
9.1944	104.6288	-10.0948	-2.8546	105.7589	-11.0855	2.3728	139.2352	-7.1311
9.1869	104.5781	-10.0462	-2.8476	105.7413	-11.0566	2.4009	139.1926	-7.2094
9.1653	104.5668	-10.0166	-2.8395	105.7391	-11.0322	2.4281	139.1982	-7.2909
9.1661	104.5057	-9.9791	-2.8252	105.7198	-10.9803	2.4407	139.1667	-7.3697
9.1715	104.5084	-9.9514	-2.8188	105.7134	-10.9631	2.4429	139.1609	-7.463
9.1428	104.4862	-9.9292	-2.8252	105.7015	-10.9394	2.4709	139.1541	-7.5019
9.1313	104.4654	-9.9148	-2.8366	105.6841	-10.9118	2.508	139.1431	-7.6085
9.1355	104.45	-9.8921	-2.8443	105.6621	-10.8908	2.5101	139.1198	-7.6475
9.1359	104.4286	-9.8417	-2.8458	105.6523	-10.8733	2.5375	139.1113	-7.7006
9.1359	104.4286	-9.8417	-2.8458	105.6523	-10.8733	2.5375	139.1113	-7.7006
9.1359	104.4286	-9.8417	-2.8464	105.6416	-10.8552	2.5193	139.1232	-7.7741
9.1382	104.4156	-9.8184	-2.8544	105.6472	-10.846	2.5799	139.0864	-7.8394
9.1526	104.4101	-9.8036	-2.8391	105.6429	-10.8297	2.5716	139.0965	-7.8811
9.1586	104.4066	-9.8001	-2.8589	105.6375	-10.8313	2.5847	139.0852	-7.9183
9.1582	104.3977	-9.7936	-2.8585	105.6494	-10.7989	2.6085	139.0753	-7.9837

9.1224	104.3704	-9.7788	-2.8436	105.6496	-10.8045	2.6021	139.0496	-8.0234
9.1303	104.3571	-9.7746	-2.8628	105.6544	-10.7856	2.6056	139.0703	-8.0599
9.1424	104.3773	-9.7604	-2.8641	105.6567	-10.7669	2.6492	139.0821	-8.098
9.1272	104.3664	-9.756	-2.8667	105.6553	-10.761	2.6452	139.079	-8.1211
9.0937	104.3618	-9.7381	-2.8756	105.6663	-10.7547	2.638	139.0715	-8.1649
9.0976	104.3556	-9.7369	-2.8756	105.6663	-10.7547	2.6566	139.0863	-8.2135
9.097	104.3525	-9.7274	-2.8953	105.6708	-10.7523	2.6552	139.0722	-8.2245
9.0932	104.3586	-9.7287	-2.8948	105.6709	-10.7402	2.6674	139.0725	-8.2409
9.0896	104.3631	-9.7268	-2.9059	105.6706	-10.7415	2.658	139.0691	-8.2495
9.085	104.3677	-9.7215	-2.9169	105.6831	-10.7295	2.6584	139.0714	-8.261
9.085	104.3677	-9.7215	-2.9239	105.6904	-10.7268	2.6488	139.0703	-8.2818
9.0736	104.368	-9.6981	-2.922	105.708	-10.7108	2.649	139.0687	-8.276
9.075	104.3724	-9.6778	-2.9279	105.7175	-10.6934	2.6459	139.0726	-8.2777
9.0693	104.3775	-9.67	-2.9393	105.7159	-10.6872	2.6459	139.0726	-8.2777
9.0514	104.3825	-9.6466	-2.9685	105.7239	-10.6575	2.6299	139.0865	-8.2505
9.0736	104.4156	-9.6228	-2.9586	105.7257	-10.6533	2.634	139.1062	-8.2487
9.0711	104.436	-9.6123	-2.9361	105.7475	-10.6316	2.6196	139.1151	-8.2263
9.0548	104.4476	-9.5988	-2.9481	105.7472	-10.5917	2.6164	139.1178	-8.2227
9.0511	104.4524	-9.5973	-2.9526	105.756	-10.553	2.6143	139.1261	-8.1981
9.0632	104.4754	-9.5472	-2.9832	105.7651	-10.5216	2.5952	139.1302	-8.1975
9.0257	104.4479	-9.5015	-2.9837	105.7768	-10.5055	2.5811	139.118	-8.1418
9.0214	104.4513	-9.4747	-2.9771	105.7832	-10.4925	2.5617	139.1145	-8.1009
9.033	104.4712	-9.4492	-2.9635	105.7914	-10.4635	2.5364	139.1329	-8.0851
9.0398	104.4857	-9.3971	-3.0173	105.7949	-10.4141	2.4804	139.1364	-8.0405
9.0375	104.5026	-9.3971	-3.0282	105.8019	-10.3902	2.4524	139.1593	-8.0198
8.9639	104.7512	-9.0252	-3.1523	105.977	-10.0065	2.2634	139.2408	-7.5154
8.9495	104.7815	-8.9471	-3.2114	106.0137	-9.9575	2.2277	139.2614	-7.4628
8.9153	104.8128	-8.9265	-3.2285	106.0099	-9.9326	2.1164	139.2526	-7.444
8.9274	104.8375	-8.9023	-3.2479	106.0253	-9.8973	2.1418	139.3194	-7.4124
8.897	104.8644	-8.8508	-3.2698	106.0737	-9.8437	2.1993	139.2777	-7.3036
8.8997	104.8942	-8.8412	-3.2697	106.1054	-9.8318	2.1973	139.286	-7.2708
8.8833	104.8932	-8.8028	-3.2906	106.1427	-9.8054	2.1874	139.291	-7.2546
8.8675	104.9186	-8.7886	-3.315	106.172	-9.7869	2.1748	139.2819	-7.2173
8.869	104.9241	-8.7439	-3.3348	106.1931	-9.7435	2.1655	139.2868	-7.1869
8.8133	104.9738	-8.7019	-3.3519	106.2289	-9.6793	2.1674	139.2674	-7.1466
8.7964	104.9902	-8.702	-3.3811	106.2654	-9.66	2.174	139.2523	-7.1322
8.7967	105.0126	-8.6904	-3.3798	106.3093	-9.6464	2.1852	139.2527	-7.1218
8.8074	105.0672	-8.6529	-3.442	106.3569	-9.6148	2.1919	139.2268	-7.0812
8.7879	105.1036	-8.6207	-3.4512	106.3965	-9.5946	2.192	139.2254	-7.0752
8.7877	105.1593	-8.5968	-3.4407	106.4461	-9.5996	2.1994	139.2043	-7.0431
8.7788	105.1761	-8.5718	-3.4781	106.5188	-9.567	2.1787	139.1855	-7.0082
8.7753	105.2229	-8.5411	-3.4565	106.611	-9.5541	2.2038	139.1521	-6.9349
8.8139	105.303	-8.5335	-3.4942	106.651	-9.5289	2.158	139.1414	-6.8942
8.8038	105.3567	-8.5063	-3.5236	106.721	-9.5034	2.1687	139.1239	-6.8309
8.8038	105.3567	-8.5063	-3.5236	106.721	-9.5034	2.1687	139.1239	-6.8309

8.8222	105.3982	-8.4683	-3.4951	106.8109	-9.4979	2.1778	139.1326	-6.8101
8.8397	105.4968	-8.4242	-3.4588	106.9079	-9.4566	2.23	139.1027	-6.6629
8.8239	105.5323	-8.3937	-3.4523	106.9966	-9.4461	2.2233	139.1109	-6.6276
8.8425	105.604	-8.3644	-3.4576	107.0352	-9.4207	2.2279	139.1084	-6.5716
8.8516	105.686	-8.311	-3.4296	107.1468	-9.3786	2.2359	139.1103	-6.4272
8.846	105.7365	-8.2799	-3.4354	107.1997	-9.3527	2.225	139.1035	-6.314
8.8646	105.8107	-8.2477	-3.419	107.2492	-9.3062	2.24	139.1024	-6.245
8.8786	105.8345	-8.1949	-3.3934	107.3016	-9.286	2.3063	139.0952	-6.1395
8.8381	105.9316	-8.1527	-3.3494	107.444	-9.2471	2.3119	139.1124	-5.9295
8.8186	106.0067	-8.1249	-3.3151	107.5191	-9.2152	2.2806	139.1156	-5.8784
8.8525	106.0485	-8.0903	-3.3188	107.579	-9.1999	2.3313	139.1403	-5.7509
8.8381	106.1228	-8.0306	-3.2922	107.6166	-9.1751	2.3268	139.1582	-5.6468
8.8063	106.1253	-8.0062	-3.2588	107.6973	-9.1258	2.3444	139.1837	-5.5523
8.8408	106.2062	-7.9799	-3.2873	107.7419	-9.1041	2.3454	139.1812	-5.447
8.8383	106.3151	-7.9038	-3.2577	107.8452	-9.0298	2.3507	139.2255	-5.2192
8.806	106.3147	-7.8724	-3.2098	107.9467	-9.0213	2.3208	139.2162	-5.104
8.7795	106.4424	-7.8284	-3.2173	108.0551	-8.9828	2.3704	139.2513	-4.8708
8.7911	106.5133	-7.8016	-3.231	108.1056	-8.9689	2.3341	139.2717	-4.7894
8.758	106.5723	-7.7829	-3.2594	108.182	-8.9351	2.3268	139.293	-4.6975
8.7101	106.6672	-7.78	-3.2587	108.2577	-8.8768	2.2933	139.3463	-4.5129
8.6685	106.6986	-7.7386	-3.2608	108.3231	-8.8556	2.3007	139.3455	-4.4196
8.6582	106.7257	-7.7301	-3.2891	108.3679	-8.837	2.2734	139.366	-4.3361
8.5525	106.8017	-7.75	-3.3311	108.4479	-8.8122	2.249	139.4121	-4.1412
8.5525	106.8017	-7.75	-3.3311	108.4479	-8.8122	2.249	139.4121	-4.1412
8.543	106.8494	-7.7691	-3.352	108.4887	-8.8004	2.1845	139.3881	-4.0378
8.4915	106.8911	-7.7793	-3.3782	108.5471	-8.7891	2.1487	139.3864	-3.9581
8.4551	106.9576	-7.7902	-3.4012	108.618	-8.7641	2.1262	139.4245	-3.7929
8.4301	106.9938	-7.8095	-3.4457	108.6587	-8.7508	2.087	139.437	-3.6868
8.3454	107.0766	-7.8539	-3.5014	108.7466	-8.7283	2.032	139.4626	-3.5117
8.32	107.0958	-7.8534	-3.5467	108.7671	-8.7076	2.036	139.4572	-3.4302
8.2914	107.1476	-7.8667	-3.59	108.8436	-8.6848	1.9757	139.4841	-3.2413
8.2391	107.1811	-7.8603	-3.6143	108.8767	-8.6804	1.9818	139.4827	-3.1572
8.1635	107.2162	-7.8992	-3.654	108.9166	-8.6582	1.989	139.5319	-3.0171
8.156	107.2274	-7.8993	-3.6624	108.9246	-8.6504	1.9177	139.5384	-2.9402
8.1474	107.2497	-7.8895	-3.6615	108.9325	-8.6394	1.8702	139.5562	-2.879
8.1472	107.2559	-7.8845	-3.6873	108.9369	-8.6331	1.8726	139.5771	-2.802
8.1348	107.2758	-7.9077	-3.6924	108.9455	-8.6175	1.8426	139.5864	-2.7284
8.1227	107.2967	-7.9141	-3.7162	108.9605	-8.5984	1.7644	139.6007	-2.6146
8.1175	107.3056	-7.9143	-3.7185	108.9705	-8.5946	1.7739	139.632	-2.5607
8.1141	107.309	-7.9101	-3.7225	108.9755	-8.5673	1.7657	139.6255	-2.5077
8.1065	107.3128	-7.8981	-3.7186	108.9798	-8.5642	1.7668	139.628	-2.4353
8.088	107.3424	-7.8764	-3.7427	108.985	-8.5255	1.6954	139.6401	-2.3101
8.0864	107.3483	-7.8848	-3.751	108.9779	-8.5042	1.6759	139.6577	-2.2897
8.0678	107.3436	-7.8787	-3.7694	109.0002	-8.4877	1.6612	139.6945	-2.2484
8.05	107.3373	-7.8656	-3.7948	108.9911	-8.4592	1.6139	139.6816	-2.1784

8.0399	107.3611	-7.8333	-3.8316	109.0028	-8.4339	1.5771	139.6786	-2.1132
8.0454	107.3798	-7.8092	-3.8593	108.9994	-8.4063	1.5434	139.6831	-2.0599
8.0454	107.3798	-7.8092	-3.8593	108.9994	-8.4063	1.5434	139.6831	-2.0599
8.0435	107.3758	-7.792	-3.8372	108.9956	-8.3819	1.5453	139.7001	-1.9962
8.0405	107.3746	-7.7778	-3.8525	109.0062	-8.3637	1.547	139.6956	-1.9736
8.0429	107.3669	-7.7675	-3.8691	109.003	-8.3498	1.5112	139.7026	-1.9433
8.0246	107.382	-7.7588	-3.87	109.0021	-8.3438	1.5034	139.7079	-1.9258
8.0347	107.3672	-7.7375	-3.8517	108.9974	-8.3191	1.4992	139.6927	-1.8587
8.0067	107.369	-7.7049	-3.8378	108.9983	-8.3111	1.4908	139.6976	-1.832
8.003	107.373	-7.7011	-3.8393	108.9866	-8.2921	1.4894	139.7122	-1.8121
7.9876	107.3925	-7.6638	-3.8371	108.9934	-8.2673	1.4717	139.715	-1.781
7.9876	107.3925	-7.6638	-3.8371	108.9934	-8.2673	1.4717	139.715	-1.781
7.987	107.3829	-7.6321	-3.8443	108.994	-8.2551	1.4479	139.7214	-1.7684
8.0141	107.3858	-7.6009	-3.846	109.0012	-8.2262	1.4508	139.7221	-1.7592
7.9993	107.353	-7.5438	-3.8427	108.9906	-8.2268	1.4392	139.7185	-1.7442
7.9993	107.353	-7.5438	-3.857	108.9599	-8.2071	1.4267	139.7228	-1.7362
7.997	107.3537	-7.5369	-3.8717	108.941	-8.1627	1.4137	139.7123	-1.7457
7.997	107.3537	-7.5369	-3.8717	108.941	-8.1627	1.4137	139.7123	-1.7457
7.9935	107.3574	-7.5332	-3.8838	108.9309	-8.1581	1.4137	139.7123	-1.7457
7.9656	107.3524	-7.5111	-3.9043	108.9201	-8.1318	1.3977	139.7192	-1.7489
7.9534	107.3421	-7.4941	-3.9178	108.9003	-8.1066	1.3673	139.7045	-1.7753
7.9568	107.3211	-7.4842	-3.9256	108.8919	-8.0821	1.3711	139.7003	-1.7756
7.9444	107.3139	-7.4638	-3.9296	108.892	-8.0729	1.3576	139.7054	-1.7786
7.9173	107.2975	-7.4302	-3.9369	108.8771	-8.0686	1.3604	139.705	-1.792
7.9154	107.2973	-7.4225	-3.9286	108.8626	-8.0383	1.3506	139.7136	-1.8094
7.8909	107.2324	-7.3771	-3.9569	108.8407	-8.0108	1.3123	139.7101	-1.8606
7.8898	107.2271	-7.3549	-3.962	108.8173	-8.0063	1.3242	139.7143	-1.8842
7.8798	107.2013	-7.3332	-3.9832	108.7946	-7.9901	1.3116	139.6963	-1.8929
7.8843	107.1499	-7.3221	-3.9884	108.7321	-7.9658	1.303	139.6821	-1.9322
7.8893	107.1375	-7.3098	-4.0101	108.7217	-7.9648	1.312	139.6849	-1.9532
7.8846	107.1041	-7.2852	-4.0309	108.6828	-7.9301	1.2955	139.6786	-1.9707
7.8563	107.0294	-7.2565	-4.0448	108.6598	-7.9156	1.2796	139.6497	-1.9905
7.8452	106.9939	-7.2273	-4.0599	108.5814	-7.8803	1.292	139.6729	-2.0141
7.8882	106.9707	-7.2129	-4.0648	108.5589	-7.8618	1.2754	139.669	-2.0471
7.8905	106.9318	-7.177	-4.0756	108.5066	-7.8305	1.2939	139.6596	-2.1043
7.8563	106.842	-7.1377	-4.1099	108.4175	-7.7864	1.2616	139.6394	-2.1624
7.8609	106.7998	-7.1233	-4.0964	108.3858	-7.7671	1.2667	139.6491	-2.1706
7.8453	106.768	-7.1288	-4.0774	108.3417	-7.7373	1.2515	139.6352	-2.1901
7.8653	106.6667	-7.1053	-4.3063	108.1869	-7.6297	1.2613	139.6588	-2.2599
7.8709	106.6474	-7.078	-4.2788	108.1519	-7.6179	1.2419	139.6488	-2.2933
7.8832	106.5242	-7.017	-4.2857	108.0371	-7.5768	1.2241	139.6553	-2.3447
7.9069	106.4698	-7.0059	-4.2607	107.9673	-7.5467	1.2294	139.6523	-2.3591
7.9069	106.4698	-7.0059	-4.2607	107.9673	-7.5467	1.2294	139.6523	-2.3591
7.8838	106.3455	-6.9765	-4.2341	107.8855	-7.4935	1.2511	139.656	-2.4373
7.9084	106.2766	-6.9474	-4.1794	107.6726	-7.4419	1.2455	139.6311	-2.4502

7.9488	106.1838	-6.9081	-4.1391	107.5769	-7.4507	1.2775	139.618	-2.5127

B.2

Sample worksheet (FL0) of loading marker data for Jack manikin motion

PSIS_L			PSIS_R			Neck_Base_Rear		
8.824	103.789	9.493	-3.320	104.986	10.809	2.299	138.694	71.524
8.835	103.782	9.464	-3.320	104.986	10.809	2.288	138.692	71.519
8.843	103.793	9.462	-3.314	104.984	10.786	2.306	138.710	71.526
8.845	103.787	9.454	-3.300	104.983	10.780	2.309	138.706	71.526
8.844	103.796	9.453	-3.296	104.963	10.750	2.288	138.700	71.503
8.836	103.785	9.422	-3.296	104.963	10.750	2.292	138.707	71.513
8.837	103.776	9.403	-3.293	104.953	10.733	2.280	138.701	71.502
8.837	103.771	9.389	-3.274	104.956	10.724	2.287	138.692	71.502
8.848	103.778	9.389	-3.276	104.955	10.715	2.283	138.696	71.496
8.850	103.784	9.374	-3.276	104.955	10.715	2.275	138.690	71.490
8.864	103.786	9.372	-3.274	104.936	10.681	2.276	138.690	71.476
8.856	103.773	9.344	-3.286	104.932	10.674	2.260	138.677	71.465
8.834	103.773	9.342	-3.286	104.932	10.674	2.240	138.673	71.459
8.831	103.774	9.337	-3.292	104.941	10.675	2.236	138.676	71.461
8.831	103.771	9.328	-3.286	104.932	10.674	2.233	138.681	71.462
8.831	103.771	9.328	-3.286	104.932	10.674	2.218	138.678	71.455
8.831	103.771	9.328	-3.291	104.936	10.663	2.224	138.672	71.451
8.833	103.763	9.315	-3.298	104.945	10.664	2.224	138.672	71.454
8.815	103.764	9.311	-3.294	104.943	10.670	2.209	138.671	71.453
8.815	103.764	9.311	-3.298	104.941	10.654	2.213	138.667	71.448
8.811	103.773	9.311	-3.301	104.950	10.661	2.209	138.671	71.451
8.811	103.773	9.311	-3.302	104.946	10.651	2.209	138.671	71.448
8.811	103.773	9.311	-3.301	104.950	10.661	2.208	138.670	71.450
8.811	103.773	9.311	-3.308	104.951	10.655	2.200	138.682	71.450
8.807	103.777	9.309	-3.343	104.962	10.664	2.201	138.673	71.448
8.798	103.772	9.317	-3.361	104.949	10.648	2.202	138.668	71.439
8.768	103.760	9.316	-3.357	104.941	10.641	2.195	138.676	71.446
8.771	103.756	9.319	-3.372	104.941	10.658	2.197	138.675	71.449
8.773	103.758	9.327	-3.391	104.929	10.666	2.196	138.677	71.446
8.773	103.761	9.337	-3.400	104.906	10.650	2.202	138.672	71.436
8.773	103.761	9.337	-3.387	104.921	10.663	2.186	138.685	71.443
8.772	103.766	9.346	-3.422	104.929	10.676	2.186	138.685	71.443
8.773	103.761	9.337	-3.403	104.931	10.685	2.187	138.669	71.442
8.767	103.750	9.354	-3.413	104.915	10.689	2.188	138.674	71.443
8.767	103.753	9.356	-3.417	104.899	10.692	2.186	138.678	71.442
8.760	103.753	9.371	-3.419	104.896	10.715	2.189	138.675	71.447
8.743	103.758	9.370	-3.400	104.901	10.727	2.179	138.670	71.449
8.742	103.754	9.376	-3.384	104.906	10.741	2.189	138.675	71.462
8.733	103.750	9.403	-3.406	104.904	10.764	2.186	138.678	71.466
8.736	103.751	9.420	-3.407	104.916	10.784	2.180	138.682	71.471
8.736	103.751	9.420	-3.409	104.923	10.794	2.172	138.695	71.478
8.736	103.755	9.429	-3.405	104.940	10.800	2.180	138.703	71.489
8.724	103.760	9.434	-3.412	104.931	10.801	2.180	138.703	71.488
8.720	103.769	9.433	-3.412	104.931	10.801	2.175	138.696	71.483
8.724	103.766	9.450	-3.396	104.940	10.807	2.180	138.703	71.491
8.724	103.766	9.450	-3.396	104.927	10.817	2.180	138.703	71.491
8.725	103.761	9.464	-3.396	104.927	10.817	2.179	138.706	71.492
8.745	103.782	9.483	-3.405	104.920	10.831	2.167	138.702	71.478
8.735	103.782	9.503	-3.433	104.923	10.843	2.166	138.707	71.482
8.730	103.795	9.517	-3.436	104.907	10.857	2.152	138.700	71.472
8.730	103.787	9.539	-3.438	104.900	10.861	2.146	138.695	71.467
8.727	103.794	9.546	-3.438	104.900	10.861	2.136	138.691	71.461
8.731	103.794	9.559	-3.452	104.912	10.896	2.139	138.699	71.473
8.718	103.791	9.566	-3.427	104.919	10.919	2.099	138.687	71.464
8.732	103.777	9.572	-3.414	104.903	10.936	2.067	138.689	71.453
8.705	103.768	9.588	-3.408	104.905	10.960	2.067	138.698	71.470
8.698	103.761	9.603	-3.408	104.905	10.960	2.070	138.697	71.473
8.689	103.750	9.604	-3.412	104.919	10.978	2.070	138.699	71.483
8.692	103.749	9.611	-3.409	104.919	10.986	2.074	138.703	71.488
8.696	103.748	9.621	-3.409	104.919	10.986	2.091	138.712	71.498
8.719	103.764	9.645	-3.419	104.913	10.992	2.082	138.722	71.491
8.724	103.768	9.673	-3.411	104.917	11.015	2.073	138.711	71.486

8.715	103.766	9.704	-3.422	104.906	11.015	2.105	138.704	71.492
8.706	103.766	9.728	-3.423	104.913	11.025	2.075	138.705	71.485
8.694	103.754	9.736	-3.422	104.916	11.047	2.063	138.707	71.491
8.684	103.747	9.782	-3.432	104.912	11.096	2.064	138.717	71.507
8.687	103.747	9.788	-3.432	104.912	11.096	2.062	138.720	71.507
8.672	103.751	9.810	-3.437	104.919	11.097	2.083	138.734	71.524
8.673	103.758	9.828	-3.444	104.942	11.121	2.081	138.737	71.532
8.704	103.772	9.879	-3.416	104.945	11.154	2.083	138.736	71.532
8.686	103.784	9.930	-3.428	104.961	11.154	2.079	138.751	71.539
8.693	103.785	9.935	-3.413	104.953	11.196	2.089	138.751	71.552
8.657	103.776	9.967	-3.423	104.966	11.235	2.100	138.751	71.574
8.663	103.776	9.986	-3.405	104.989	11.247	2.122	138.762	71.594
8.694	103.817	10.048	-3.411	104.981	11.252	2.121	138.764	71.579
8.722	103.850	10.144	-3.388	105.001	11.283	2.139	138.766	71.585
8.723	103.891	10.233	-3.375	105.007	11.290	2.138	138.759	71.574
8.706	103.917	10.206	-3.336	105.018	11.325	2.141	138.750	71.587
8.739	103.918	10.274	-3.315	105.050	11.400	2.164	138.764	71.619
8.733	103.903	10.274	-3.313	105.072	11.440	2.183	138.781	71.652
8.753	103.921	10.366	-3.325	105.104	11.473	2.205	138.795	71.668
8.796	103.951	10.431	-3.328	105.129	11.521	2.216	138.813	71.681
8.796	103.951	10.431	-3.322	105.147	11.562	2.248	138.836	71.719
8.792	103.981	10.474	-3.294	105.186	11.597	2.236	138.861	71.738
8.796	104.012	10.501	-3.287	105.224	11.628	2.242	138.878	71.757
8.826	104.038	10.544	-3.251	105.278	11.692	2.248	138.900	71.786
8.856	104.054	10.592	-3.271	105.295	11.717	2.269	138.908	71.795
8.874	104.058	10.626	-3.252	105.309	11.774	2.257	138.907	71.802
8.919	104.090	10.693	-3.233	105.325	11.803	2.277	138.917	71.809
8.857	104.217	10.834	-3.197	105.345	11.854	2.280	138.927	71.823
8.882	104.192	10.847	-3.187	105.391	11.920	2.287	138.933	71.851
8.928	104.204	10.909	-3.156	105.415	11.974	2.294	138.946	71.866
8.939	104.201	10.893	-3.151	105.438	12.037	2.303	138.955	71.893
8.992	104.239	10.957	-3.142	105.453	12.087	2.326	138.980	71.911
8.983	104.259	10.995	-3.087	105.487	12.162	2.330	138.987	71.943
9.006	104.289	11.044	-3.057	105.520	12.205	2.331	138.994	71.954
9.045	104.309	11.094	-3.059	105.554	12.267	2.314	139.007	71.961
9.052	104.332	11.151	-3.030	105.576	12.307	2.319	139.040	71.988
9.079	104.385	11.230	-3.014	105.604	12.382	2.338	139.042	72.004
9.095	104.417	11.264	-2.951	105.641	12.480	2.326	139.051	72.031
9.116	104.468	11.344	-2.939	105.675	12.554	2.327	139.082	72.056
9.162	104.499	11.426	-2.905	105.713	12.637	2.304	139.117	72.076
9.193	104.598	11.485	-2.888	105.750	12.697	2.259	139.133	72.065
9.222	104.638	11.585	-2.848	105.810	12.827	2.241	139.161	72.102
9.253	104.682	11.650	-2.854	105.841	12.886	2.189	139.183	72.095
9.307	104.777	11.732	-2.863	105.887	13.005	2.189	139.208	72.115
9.297	104.845	11.839	-2.855	105.943	13.099	2.161	139.228	72.134
9.284	104.935	11.959	-2.829	106.039	13.230	2.123	139.259	72.170
9.329	105.034	12.061	-2.856	106.083	13.287	2.105	139.320	72.183
9.323	105.094	12.169	-2.893	106.185	13.397	2.077	139.351	72.215
9.287	105.153	12.262	-2.903	106.249	13.469	2.000	139.353	72.207
9.251	105.233	12.390	-2.845	106.355	13.588	2.006	139.427	72.289
9.294	105.311	12.506	-2.926	106.431	13.649	1.969	139.434	72.272
9.247	105.388	12.586	-2.922	106.526	13.748	1.941	139.485	72.321
9.214	105.454	12.683	-2.933	106.607	13.807	1.921	139.546	72.362
9.181	105.502	12.752	-2.960	106.661	13.836	1.887	139.561	72.367
9.203	105.599	12.833	-2.956	106.721	13.874	1.839	139.596	72.362
9.170	105.661	12.911	-2.963	106.834	13.938	1.811	139.619	72.391
9.162	105.729	12.944	-2.929	106.915	13.977	1.782	139.631	72.403
9.166	105.810	12.991	-2.945	106.950	13.995	1.733	139.653	72.389
9.156	105.837	13.021	-2.973	106.985	14.021	1.705	139.656	72.386
9.115	105.862	13.065	-3.011	107.041	14.029	1.699	139.675	72.403
9.095	105.906	13.087	-3.014	107.082	14.063	1.664	139.669	72.399
9.075	105.984	13.110	-3.026	107.108	14.070	1.628	139.683	72.389
9.076	106.013	13.123	-3.048	107.170	14.075	1.621	139.722	72.409
9.068	106.032	13.139	-3.055	107.194	14.076	1.628	139.696	72.402
9.061	106.043	13.141	-3.060	107.249	14.081	1.633	139.720	72.426
9.053	106.059	13.144	-3.029	107.298	14.068	1.633	139.720	72.433
9.051	106.074	13.149	-3.037	107.317	14.054	1.637	139.740	72.442

9.057	106.098	13.137	-3.042	107.320	14.046	1.595	139.738	72.418
9.043	106.127	13.116	-3.019	107.331	14.039	1.615	139.740	72.430
9.035	106.158	13.106	-3.041	107.357	14.009	1.603	139.743	72.419
9.019	106.160	13.098	-3.057	107.360	14.012	1.590	139.748	72.420
8.994	106.161	13.068	-3.051	107.371	13.977	1.593	139.746	72.420
9.003	106.165	13.028	-3.066	107.391	13.956	1.608	139.755	72.427
9.010	106.162	12.994	-3.070	107.402	13.949	1.585	139.757	72.420
9.009	106.158	12.984	-3.077	107.415	13.891	1.584	139.760	72.409
9.002	106.164	12.965	-3.096	107.398	13.853	1.564	139.772	72.395
8.982	106.150	12.938	-3.114	107.393	13.841	1.552	139.768	72.390
8.975	106.144	12.921	-3.131	107.383	13.794	1.557	139.762	72.376
8.951	106.135	12.873	-3.139	107.363	13.750	1.552	139.768	72.371
8.937	106.107	12.802	-3.118	107.349	13.695	1.566	139.772	72.375
8.927	106.097	12.787	-3.136	107.343	13.659	1.565	139.771	72.367
8.934	106.100	12.767	-3.139	107.333	13.637	1.582	139.772	72.366
8.951	106.076	12.713	-3.146	107.305	13.584	1.606	139.775	72.361
8.950	106.091	12.660	-3.159	107.292	13.535	1.600	139.756	72.335
8.945	106.064	12.605	-3.161	107.281	13.503	1.607	139.762	72.339
8.955	106.054	12.572	-3.171	107.238	13.452	1.612	139.772	72.325
8.932	106.055	12.517	-3.166	107.226	13.399	1.642	139.772	72.330
8.936	106.025	12.448	-3.177	107.204	13.340	1.647	139.744	72.306
8.949	106.010	12.420	-3.163	107.179	13.289	1.684	139.768	72.317
8.966	105.971	12.366	-3.164	107.155	13.262	1.675	139.765	72.306
8.984	105.950	12.311	-3.149	107.133	13.214	1.710	139.768	72.310
8.975	105.937	12.272	-3.140	107.102	13.154	1.746	139.772	72.313
8.958	105.891	12.203	-3.149	107.083	13.121	1.756	139.776	72.319
8.952	105.867	12.154	-3.101	107.057	13.070	1.782	139.756	72.315
8.977	105.831	12.094	-3.103	107.037	13.014	1.815	139.741	72.306
9.020	105.796	12.013	-3.080	106.999	12.955	1.823	139.747	72.294
9.003	105.752	11.981	-3.076	106.952	12.889	1.841	139.753	72.290
9.027	105.736	11.910	-3.108	106.919	12.835	1.895	139.753	72.291
9.022	105.704	11.841	-3.093	106.904	12.766	1.887	139.732	72.268
9.039	105.681	11.786	-3.094	106.859	12.710	1.895	139.735	72.254
9.031	105.643	11.701	-3.061	106.856	12.678	1.938	139.708	72.264
9.070	105.608	11.634	-3.044	106.791	12.609	1.946	139.703	72.239
9.088	105.594	11.613	-3.010	106.757	12.549	1.971	139.694	72.227
9.100	105.568	11.542	-3.008	106.739	12.494	2.013	139.696	72.233
9.107	105.528	11.474	-3.002	106.728	12.462	2.036	139.665	72.225
9.107	105.532	11.438	-2.997	106.687	12.369	2.045	139.684	72.210
9.101	105.456	11.372	-2.983	106.619	12.309	2.038	139.649	72.180
9.115	105.437	11.324	-2.993	106.592	12.282	2.067	139.636	72.175
9.152	105.414	11.274	-2.962	106.551	12.197	2.074	139.622	72.144
9.148	105.364	11.206	-2.989	106.527	12.141	2.125	139.630	72.159
9.135	105.343	11.164	-2.985	106.505	12.107	2.145	139.611	72.154
9.147	105.320	11.090	-3.018	106.470	12.077	2.167	139.605	72.148
9.152	105.302	11.063	-2.982	106.419	11.999	2.184	139.589	72.125
9.169	105.298	10.995	-2.940	106.390	11.923	2.188	139.583	72.105
9.157	105.264	10.938	-2.923	106.387	11.881	2.199	139.568	72.103
9.172	105.211	10.888	-2.908	106.368	11.841	2.240	139.543	72.102
9.195	105.196	10.871	-2.976	106.326	11.779	2.242	139.544	72.073
9.168	105.181	10.826	-2.964	106.310	11.744	2.242	139.540	72.070
9.176	105.132	10.776	-2.959	106.279	11.699	2.233	139.516	72.047
9.184	105.094	10.719	-2.959	106.238	11.661	2.248	139.515	72.042
9.151	105.056	10.703	-2.964	106.206	11.622	2.288	139.509	72.053
9.142	105.035	10.673	-2.952	106.188	11.561	2.297	139.490	72.037
9.148	105.007	10.630	-2.953	106.168	11.528	2.277	139.451	72.003
9.162	104.986	10.577	-2.935	106.135	11.497	2.268	139.436	71.984
9.178	104.975	10.544	-2.911	106.078	11.441	2.261	139.430	71.956
9.167	104.935	10.502	-2.904	106.046	11.397	2.294	139.405	71.952
9.169	104.891	10.480	-2.930	106.003	11.340	2.275	139.398	71.923
9.177	104.862	10.407	-2.922	105.987	11.326	2.297	139.375	71.922
9.199	104.832	10.368	-2.912	105.971	11.281	2.295	139.355	71.900
9.179	104.803	10.328	-2.907	105.938	11.234	2.305	139.345	71.892
9.159	104.771	10.314	-2.900	105.930	11.216	2.288	139.329	71.882
9.171	104.751	10.254	-2.883	105.862	11.156	2.317	139.321	71.868
9.171	104.714	10.226	-2.872	105.835	11.136	2.372	139.319	71.887
9.179	104.691	10.198	-2.874	105.836	11.128	2.373	139.298	71.879

9.178	104.682	10.174	-2.872	105.797	11.119	2.370	139.269	71.858
9.198	104.679	10.147	-2.863	105.787	11.109	2.364	139.232	71.832
9.194	104.629	10.095	-2.855	105.759	11.085	2.373	139.235	71.837
9.195	104.609	10.069	-2.851	105.748	11.077	2.389	139.216	71.835
9.187	104.578	10.046	-2.848	105.741	11.057	2.401	139.193	71.830
9.165	104.567	10.017	-2.839	105.739	11.032	2.428	139.198	71.845
9.172	104.535	9.983	-2.827	105.720	10.995	2.466	139.194	71.852
9.166	104.506	9.979	-2.825	105.720	10.980	2.441	139.167	71.830
9.172	104.508	9.951	-2.819	105.713	10.963	2.443	139.161	71.824
9.143	104.486	9.929	-2.825	105.702	10.939	2.471	139.154	71.833
9.149	104.466	9.929	-2.842	105.692	10.936	2.494	139.148	71.837
9.131	104.465	9.915	-2.837	105.684	10.912	2.508	139.143	71.838
9.135	104.450	9.892	-2.844	105.662	10.891	2.510	139.120	71.820
9.135	104.440	9.866	-2.851	105.652	10.884	2.508	139.106	71.812
9.136	104.429	9.842	-2.846	105.652	10.873	2.537	139.111	71.827
9.136	104.429	9.842	-2.846	105.642	10.855	2.519	139.123	71.819
9.134	104.413	9.841	-2.841	105.660	10.857	2.560	139.095	71.828
9.138	104.416	9.818	-2.854	105.647	10.846	2.580	139.086	71.826
9.153	104.410	9.804	-2.839	105.643	10.830	2.572	139.096	71.823
9.159	104.407	9.800	-2.859	105.638	10.831	2.585	139.085	71.819
9.134	104.395	9.800	-2.838	105.648	10.820	2.608	139.075	71.831
9.158	104.398	9.794	-2.858	105.649	10.799	2.609	139.075	71.820
9.122	104.370	9.779	-2.844	105.650	10.805	2.602	139.050	71.820
9.124	104.371	9.785	-2.857	105.642	10.792	2.609	139.064	71.823
9.130	104.357	9.775	-2.863	105.654	10.786	2.606	139.070	71.826
9.142	104.377	9.760	-2.864	105.657	10.767	2.649	139.082	71.840
9.127	104.366	9.756	-2.867	105.655	10.761	2.645	139.079	71.840
9.128	104.378	9.746	-2.873	105.654	10.751	2.644	139.072	71.832
9.094	104.362	9.738	-2.876	105.666	10.755	2.638	139.072	71.841
9.098	104.356	9.737	-2.876	105.666	10.755	2.657	139.086	71.856
9.097	104.352	9.727	-2.895	105.671	10.752	2.655	139.072	71.848
9.093	104.359	9.729	-2.895	105.671	10.740	2.667	139.073	71.850
9.090	104.363	9.727	-2.906	105.671	10.742	2.658	139.069	71.844
9.090	104.363	9.727	-2.910	105.674	10.742	2.660	139.067	71.844
9.085	104.368	9.722	-2.917	105.683	10.730	2.658	139.071	71.844
9.085	104.368	9.722	-2.924	105.690	10.727	2.649	139.070	71.840
9.074	104.368	9.698	-2.922	105.708	10.711	2.649	139.069	71.842
9.074	104.377	9.687	-2.932	105.705	10.713	2.650	139.070	71.841
9.075	104.372	9.678	-2.928	105.718	10.693	2.646	139.073	71.839
9.069	104.378	9.670	-2.939	105.716	10.687	2.646	139.073	71.837
9.069	104.387	9.659	-2.953	105.725	10.680	2.642	139.075	71.835
9.051	104.382	9.647	-2.968	105.724	10.658	2.630	139.087	71.833
9.074	104.416	9.623	-2.959	105.726	10.653	2.634	139.106	71.837
9.071	104.436	9.612	-2.936	105.747	10.632	2.620	139.115	71.834
9.055	104.448	9.599	-2.948	105.747	10.592	2.616	139.118	71.826
9.051	104.452	9.597	-2.953	105.756	10.553	2.614	139.126	71.821
9.063	104.475	9.547	-2.983	105.765	10.522	2.595	139.130	71.803
9.049	104.458	9.525	-2.969	105.768	10.519	2.591	139.123	71.805
9.026	104.448	9.501	-2.984	105.777	10.506	2.581	139.118	71.803
9.021	104.451	9.475	-2.977	105.783	10.493	2.562	139.114	71.794
9.033	104.471	9.449	-2.963	105.791	10.463	2.536	139.133	71.785
9.037	104.475	9.428	-3.004	105.786	10.431	2.495	139.124	71.751
9.040	104.486	9.397	-3.017	105.795	10.414	2.480	139.136	71.747
9.037	104.503	9.397	-3.028	105.802	10.390	2.452	139.159	71.739
9.031	104.528	9.350	-3.028	105.803	10.369	2.448	139.154	71.730
9.014	104.533	9.301	-3.024	105.824	10.342	2.418	139.162	71.725
9.016	104.566	9.266	-3.038	105.864	10.325	2.385	139.166	71.712
9.032	104.599	9.257	-3.064	105.867	10.293	2.399	139.186	71.710
9.043	104.619	9.252	-3.072	105.882	10.261	2.394	139.185	71.697
9.037	104.626	9.244	-3.079	105.888	10.226	2.367	139.195	71.683
9.005	104.634	9.189	-3.090	105.901	10.206	2.350	139.196	71.682
9.005	104.649	9.132	-3.094	105.912	10.178	2.326	139.199	71.669
9.001	104.661	9.113	-3.099	105.921	10.142	2.331	139.198	71.663
8.979	104.692	9.069	-3.089	105.928	10.104	2.319	139.235	71.672
8.969	104.700	9.056	-3.108	105.929	10.068	2.284	139.235	71.649
8.968	104.715	9.047	-3.125	105.960	10.039	2.248	139.242	71.633
8.964	104.751	9.025	-3.152	105.977	10.007	2.263	139.241	71.628

8.975	104.788	8.977	-3.181	106.009	9.981	2.240	139.249	71.615
8.950	104.781	8.947	-3.211	106.014	9.958	2.228	139.261	71.616
8.915	104.813	8.927	-3.229	106.010	9.933	2.116	139.253	71.562
8.927	104.837	8.902	-3.248	106.025	9.897	2.142	139.319	71.592
8.909	104.847	8.874	-3.250	106.042	9.890	2.203	139.271	71.599
8.897	104.864	8.851	-3.270	106.074	9.844	2.199	139.278	71.594
8.900	104.894	8.841	-3.270	106.105	9.832	2.197	139.286	71.595
8.883	104.893	8.803	-3.291	106.143	9.805	2.187	139.291	71.597
8.868	104.919	8.789	-3.315	106.172	9.787	2.175	139.282	71.587
8.869	104.924	8.744	-3.335	106.193	9.744	2.165	139.287	71.578
8.845	104.951	8.717	-3.336	106.199	9.717	2.172	139.284	71.576
8.813	104.974	8.702	-3.352	106.229	9.679	2.167	139.267	71.565
8.796	104.990	8.702	-3.381	106.265	9.660	2.174	139.252	71.561
8.797	105.013	8.690	-3.380	106.309	9.646	2.185	139.253	71.567
8.786	105.034	8.671	-3.417	106.332	9.625	2.182	139.242	71.556
8.807	105.067	8.653	-3.442	106.357	9.615	2.192	139.227	71.545
8.788	105.104	8.621	-3.451	106.397	9.595	2.192	139.225	71.546
8.788	105.159	8.597	-3.441	106.446	9.600	2.199	139.204	71.544
8.779	105.176	8.572	-3.478	106.519	9.567	2.179	139.185	71.528
8.787	105.212	8.557	-3.458	106.581	9.571	2.187	139.174	71.534
8.775	105.223	8.541	-3.457	106.611	9.554	2.204	139.152	71.534
8.814	105.303	8.533	-3.494	106.651	9.529	2.158	139.141	71.489
8.804	105.357	8.506	-3.524	106.721	9.503	2.169	139.124	71.484
8.822	105.398	8.468	-3.495	106.811	9.498	2.178	139.133	71.502
8.800	105.408	8.428	-3.472	106.863	9.465	2.199	139.137	71.521
8.840	105.497	8.424	-3.459	106.908	9.457	2.230	139.103	71.504
8.824	105.532	8.394	-3.452	106.997	9.446	2.223	139.111	71.519
8.843	105.604	8.364	-3.458	107.035	9.421	2.228	139.108	71.508
8.870	105.647	8.346	-3.425	107.104	9.398	2.242	139.112	71.514
8.852	105.686	8.311	-3.430	107.147	9.379	2.236	139.110	71.514
8.846	105.736	8.280	-3.435	107.200	9.353	2.225	139.103	71.504
8.865	105.811	8.248	-3.419	107.249	9.306	2.240	139.102	71.497
8.879	105.835	8.195	-3.393	107.302	9.286	2.306	139.095	71.523
8.867	105.894	8.174	-3.379	107.383	9.292	2.313	139.121	71.551
8.838	105.932	8.153	-3.349	107.444	9.247	2.312	139.112	71.551
8.819	106.007	8.125	-3.315	107.519	9.215	2.281	139.116	71.544
8.852	106.048	8.090	-3.319	107.579	9.200	2.331	139.140	71.571
8.838	106.123	8.031	-3.292	107.617	9.175	2.327	139.158	71.578
8.806	106.125	8.006	-3.259	107.697	9.126	2.344	139.184	71.609
8.841	106.206	7.980	-3.287	107.742	9.104	2.345	139.181	71.592
8.826	106.270	7.947	-3.267	107.802	9.059	2.330	139.214	71.599
8.838	106.315	7.904	-3.258	107.845	9.030	2.351	139.226	71.608
8.806	106.315	7.872	-3.210	107.947	9.021	2.321	139.216	71.620
8.786	106.402	7.846	-3.233	108.010	8.995	2.354	139.224	71.633
8.779	106.442	7.828	-3.217	108.055	8.983	2.370	139.251	71.656
8.791	106.513	7.802	-3.231	108.106	8.969	2.334	139.272	71.645
8.758	106.572	7.783	-3.259	108.182	8.935	2.327	139.293	71.654
8.714	106.623	7.798	-3.258	108.228	8.926	2.304	139.325	71.668
8.710	106.667	7.780	-3.259	108.258	8.877	2.293	139.346	71.662

B.3
Sample worksheet of calculating dynamic information

Bend in Medial Plane							**Max Angle:**	9.81723					**Max Angular Speed:**		**14.80751**
104.3796	-10.1013	138.6996	-6.9614	5.227369	0		**Min Angle**	-2.0803					**Min Anglular Speed:**		-26.925
104.3643	-10.068	138.701	-6.9515	5.186116	-0.04125		**Average:**	2.297647					**Average Angular Speed:**		-0.85698
104.3632	-10.0564	138.692	-6.9303	5.203195	-0.02417										
104.3666	-10.0523	138.6957	-6.9308	5.195542	-0.03183	-0.05349	0.038927291	**-0.05425**							
104.3609	-10.0263	138.69	-6.9344	5.146534	-0.08084	-0.06731	0.03357828	**-0.06537**							
104.3527	-10.0089	138.6772	-6.9294	5.126604	-0.10077	-0.07735	0.034966506	**-0.07144**							
104.3526	-10.0082	138.6727	-6.926	5.131812	-0.09556	-0.08815	0.02644251	**-0.08343**	-0.08233	0.019236	-0.08206				
104.3577	-10.0059	138.6763	-6.9245	5.130628	-0.09674	-0.09785	0.009118823	**-0.09733**	-0.0898	0.016476	-0.08848				
104.3516	-10.0008	138.6806	-6.9274	5.115843	-0.11153	-0.10178	0.005925162	**-0.10042**	-0.09627	0.013984	-0.09493				
104.3516	-10.0007	138.6784	-6.9205	5.127593	-0.09978	-0.10422	0.008433444	**-0.10406**	-0.10198	0.009637	-0.10134	-0.09958	0.011612	-0.099238013	
104.3516	-10.0008	138.6784	-6.9205	5.127595	-0.09977	-0.10702	0.008326034	**-0.10658**	-0.10667	0.006621	-0.10664	-0.10448	0.010137	-0.104050325	**0.288739**
104.3536	-9.99545	138.672	-6.9211	5.119071	-0.1083	-0.11082	0.008910942	**-0.11065**	-0.11003	0.00706	-0.1101	-0.10901	0.008782	-0.10873389	**0.281014**
104.3539	-9.98965	138.672	-6.9211	5.109502	-0.11787	-0.11223	0.009781146	**-0.11138**	-0.11333	0.007204	-0.11349	-0.11303	0.007633	-0.112935596	**0.252102**
104.3532	-9.9906	138.6713	-6.9204	5.112242	-0.11513	-0.11663	0.010160309	**-0.11625**	-0.11638	0.007145	-0.11639	-0.1166	0.00707	-0.116594736	**0.219548**
104.3524	-9.9824	138.6668	-6.9175	5.104004	-0.12337	-0.12103	0.008113874	**-0.1209**	-0.12016	0.008039	-0.12016	-0.11963	0.006637	-0.119555512	**0.177647**
104.3612	-9.9861	138.6713	-6.9204	5.105965	-0.1214	-0.12144	0.007404286	**-0.12348**	-0.12315	0.007798	-0.12309	-0.12267	0.00641	-0.122579639	**0.181448**
104.3592	-9.98075	138.6713	-6.9204	5.096814	-0.13056	-0.1238	0.008612684	**-0.12541**	-0.12631	0.006629	-0.1263	-0.12585	0.006607	-0.125841548	**0.195715**
104.3619	-9.98275	138.6822	-6.9217	5.096762	-0.13061	-0.12903	0.012632462	**-0.13304**	-0.12868	0.005263	-0.12792	-0.12919	0.006926	-0.129358414	**0.211012**
104.3696	-9.9863	138.6733	-6.915	5.116199	-0.11117	-0.13161	0.013114038	**-0.13156**	-0.13158	0.00583	-0.13137	-0.13242	0.007285	-0.132570581	**0.19273**
104.3605	-9.9822	138.6678	-6.9246	5.092967	-0.1344	-0.13382	0.012390971	**-0.13349**	-0.13509	0.007333	-0.13572	-0.1359	0.007875	-0.135962384	**0.203508**
104.3505	-9.9785	138.6763	-6.9297	5.075655	-0.15171	-0.13624	0.013276245	**-0.13286**	-0.13919	0.008892	-0.13975	-0.13968	0.008789	-0.139726267	**0.225833**
104.3483	-9.9881	138.6749	-6.933	5.085971	-0.1414	-0.14196	0.018175318	**-0.14122**	-0.14258	0.010522	-0.14281	-0.14412	0.009666	-0.14432009	**0.275629**
104.3432	-9.9967	138.6772	-6.9382	5.090509	-0.13686	-0.14777	0.012212154	**-0.14803**	-0.14747	0.012345	-0.14744	-0.1485	0.009879	-0.148670332	**0.261014**
104.3332	-9.99325	138.6717	-6.9408	5.079838	-0.14753	-0.1533	0.013802883	**-0.15415**	-0.15285	0.013407	-0.15274	-0.15245	0.009437	-0.152368168	**0.22187**
104.3408	-9.99985	138.6847	-6.9609	5.056697	-0.17067	-0.15749	0.017264371	**-0.15674**	-0.1589	0.012404	-0.159	-0.15579	0.008253	-0.155197013	**0.169731**
104.3475	-10.0107	138.6847	-6.9609	5.075552	-0.15182	-0.16598	0.022003488	**-0.16579**	-0.16245	0.009771	-0.16206	-0.15841	0.006061	-0.157454562	**0.135453**
104.346	-10.0106	138.669	-6.975	5.054285	-0.17308	-0.17149	0.017951707	**-0.17118**	-0.1641	0.00768	-0.16339	-0.15863	0.005597	-0.159174022	**0.103168**
104.3323	-10.0215	138.6736	-6.989	5.04631	-0.18106	-0.17158	0.017812003	**-0.17523**	-0.16166	0.012534	-0.16311	-0.15511	0.012915	-0.15937627	**0.012135**
104.3259	-10.0241	138.6775	-7.0027	5.026516	-0.20085	-0.16185	0.031653864	**-0.16601**	-0.15376	0.026165	-0.16111	-0.14648	0.024688	-0.153251641	**-0.36748**
104.3246	-10.0429	138.675	-7.0062	5.051931	-0.17544	-0.14695	0.053879503	**-0.1596**	-0.13878	0.042846	-0.14901	-0.13272	0.037874	-0.141030372	**-0.73328**
104.33	-10.0589	138.675	-7.0062	5.079205	-0.14816	-0.12754	0.066009627	**-0.13709**	-0.11915	0.055214	-0.12806	-0.11467	0.04922	-0.121861944	**-1.15011**
104.3274	-10.0834	138.6775	-7.0027	5.124872	-0.1025	-0.10118	0.077002687	**-0.10145**	-0.09519	0.062703	-0.0986	-0.09322	0.056745	-0.096308071	**-1.53323**
104.3337	-10.1017	138.6816	-6.988	5.179802	-0.04757	-0.07133	0.072281903	**-0.0609**	-0.07021	0.064605	-0.06574	-0.06946	0.058366	-0.06755475	**-1.7252**
104.3372	-10.1067	138.6954	-6.9858	5.190174	-0.0372	-0.04314	0.062757953	**-0.03379**	-0.0446	0.058501	-0.03707	-0.0457	0.054299	-0.0403266	**-1.63369**
104.3479	-10.1146	138.7035	-6.9693	5.230831	0.003462	-0.01702	0.048105598	**-0.00752**	-0.02074	0.047524	-0.01292	-0.02365	0.045992	-0.017004273	**-1.39934**
104.3453	-10.1176	138.7035	-6.9693	5.235481	0.008112	0.002583	0.033076179	**0.008912**	-0.00145	0.03507	0.00516	-0.00561	0.03518	0.001093727	**-1.08588**
104.3501	-10.1173	138.6962	-6.9618	5.249226	0.021857	0.014602	0.026434072	**0.019641**	0.012172	0.025286	0.017313	0.007384	0.024425	0.013477909	**-0.74305**
104.3467	-10.1336	138.7035	-6.9693	5.262078	0.034708	0.02513	0.014220331	**0.029957**	0.021941	0.016119	0.026336	0.016061	0.014956	0.021379764	**-0.47411**
104.3467	-10.1335	138.7035	-6.9693	5.262076	0.034707	0.029518	0.010730767	**0.033535**	0.025826	0.009919	0.027628	0.02081	0.00777	0.024136945	**-0.16543**
104.3439	-10.1405	138.7059	-6.9746	5.263931	0.036562	0.032811	0.005155511	**0.034468**	0.026152	0.009287	0.025238	0.022215	0.004783	0.022674605	**0.08774**
104.3513	-10.1566	138.7023	-6.9918	5.263871	0.036501	0.034878	0.001911912	**0.034596**	0.024259	0.011836	0.023676	0.020372	0.008231	0.019709345	**0.177916**
104.3525	-10.1726	138.7068	-7.0089	5.261549	0.034179	0.025249	0.025621134	**0.019673**	0.020315	0.01402	0.020317	0.014984	0.013999	0.013883048	**0.349578**
104.351	-10.187	138.6996	-7.0256	5.25853	0.031161	0.01678	0.031170389	**0.011196**	0.01446	0.015998	0.014999	0.007491	0.019181	0.006316561	**0.453989**
104.3434	-10.2001	138.6955	-7.0353	5.263696	0.036326	0.00768	0.033634652	**0.006389**	0.004978	0.021039	0.004409	-0.0015	0.023698	-0.002321721	**0.518297**
104.3528	-10.2278	138.6992	-7.1052	5.194677	-0.03269	-0.00269	0.03444335	**0.002345**	-0.00901	0.029067	-0.01138	-0.01209	0.026917	-0.012348413	**0.601602**
104.355	-10.2428	138.687	-7.1166	5.202795	-0.02457	-0.01363	0.032909476	**-0.00745**	-0.02286	0.03552	-0.02482	-0.02473	0.029779	-0.024781857	**0.746007**
104.3402	-10.254	138.6887	-7.1279	5.200227	-0.02714	-0.03212	0.039304477	**-0.03191**	-0.0371	0.03936	-0.03771	-0.03987	0.032977	-0.040395904	**0.936843**
104.3369	-10.2741	138.698	-7.1522	5.191309	-0.03606	-0.05759	0.044917967	**-0.06328**	-0.05214	0.040079	-0.05046	-0.05651	0.036147	-0.057518743	**1.02737**
104.3349	-10.2912	138.6991	-7.1729	5.184973	-0.0424	-0.07461	0.055294702	**-0.07732**	-0.0699	0.03945	-0.06814	-0.07311	0.03857	-0.073812424	**0.977621**
104.3341	-10.2985	138.7034	-7.2135	5.12906	-0.09831	-0.08943	0.053518578	**-0.08847**	-0.09046	0.038981	-0.09096	-0.08958	0.039141	-0.0893883	**0.934553**

104.3333	-10.3035	138.712	-7.2441	5.085421	-0.14195	-0.10622	0.048964809	**-0.09888**	-0.11046	0.039838	-0.11206	-0.1057	0.037413	-0.104540003	**0.909102**
104.3382	-10.3184	138.7225	-7.2645	5.075504	-0.15187	-0.12798	0.046366998	**-0.12196**	-0.12698	0.040984	-0.12758	-0.12153	0.033365	-0.1201988	**0.939528**
104.3424	-10.3444	138.7114	-7.2776	5.09908	-0.12829	-0.15022	0.034202801	**-0.15137**	-0.14176	0.038677	-0.14018	-0.13592	0.027745	-0.134958525	**0.885584**
104.3393	-10.377	138.7051	-7.3204	5.082681	-0.14469	-0.17012	0.039148325	**-0.1719**	-0.15452	0.032393	-0.15054	-0.14767	0.022444	-0.146969717	**0.720672**
104.3351	-10.3918	138.7074	-7.361	5.038978	-0.18839	-0.17965	0.039268509	**-0.17896**	-0.16558	0.021673	-0.16127	-0.15498	0.016441	-0.153786945	**0.409034**
104.3296	-10.4388	138.7174	-7.4125	5.029353	-0.19802	-0.17855	0.040270821	**-0.18075**	-0.17021	0.012189	-0.16885	-0.1575	0.012397	-0.157142148	**0.201312**
104.335	-10.4534	138.7339	-7.4501	4.989721	-0.23765	-0.18026	0.037971493	**-0.17783**	-0.16636	0.020546	-0.17323	-0.1543	0.018832	-0.15803478	**0.053558**
104.3497	-10.4744	138.7375	-7.4545	5.018696	-0.20867	-0.1681	0.059046891	**-0.17631**	-0.15335	0.037925	-0.16319	-0.14473	0.032849	-0.152810508	**-0.31346**
104.3588	-10.5166	138.7357	-7.4587	5.083198	-0.14417	-0.15088	0.06890006	**-0.15437**	-0.13489	0.052167	-0.14522	-0.12877	0.047393	-0.137427569	**-0.92298**
104.3728	-10.5421	138.7506	-7.4817	5.087124	-0.14025	-0.12529	0.080719224	**-0.12438**	-0.11144	0.063712	-0.11778	-0.10669	0.059958	-0.11297575	**-1.46711**
104.3709	-10.6008	138.7514	-7.4914	5.167809	-0.05956	-0.08482	0.085851557	**-0.08085**	-0.08292	0.073057	-0.08358	-0.07837	0.069353	-0.082124167	**-1.8511**
104.3826	-10.6166	138.7616	-7.5123	5.159528	-0.06784	-0.04768	0.079341808	**-0.04971**	-0.05021	0.075488	-0.04955	-0.04403	0.079178	-0.047987128	**-2.04822**
104.3989	-10.6502	138.7636	-7.5176	5.208454	-0.01892	-0.02091	0.072686373	**-0.01666**	-0.00992	0.085255	-0.01426	-0.00172	0.09386	-0.010203168	**-2.26704**
104.4254	-10.7135	138.7658	-7.5441	5.273006	0.045637	0.028945	0.093815888	**0.021868**	0.04103	0.108775	0.024951	0.050305	0.116919	0.034810225	**-2.7008**
104.4489	-10.7614	138.7589	-7.5914	5.278728	0.051359	0.090203	0.14972889	**0.052646**	0.103417	0.146068	0.077206	0.113358	0.147657	0.092521491	**-3.46268**
104.4674	-10.7655	138.7502	-7.6029	5.270547	0.043178	0.168734	0.191385672	**0.127646**	0.178767	0.184813	0.150933	0.188354	0.180737	0.16675016	**-4.45372**
104.4873	-10.8571	138.7807	-7.5936	5.43613	0.20876	0.259418	0.233426101	**0.232267**	0.266238	0.218697	0.246428	0.274977	0.210331	0.258021236	**-5.47626**
104.5127	-10.9197	138.7948	-7.5603	5.596616	0.369247	0.349471	0.257553157	**0.355867**	0.36359	0.242198	0.357794	0.372445	0.232115	0.36314135	**-6.30721**
104.5403	-10.9763	138.8134	-7.5498	5.709244	0.481875	0.461258	0.27577051	**0.477733**	0.4734	0.251787	0.475421	0.479235	0.245233	0.476179269	**-6.78228**
104.5837	-11.0358	138.861	-7.5279	5.843243	0.615873	0.58419	0.248823794	**0.59564**	0.589446	0.253066	0.592106	0.592581	0.251482	0.59186727	**-6.94128**
104.6181	-11.0646	138.8779	-7.5221	5.903374	0.676004	0.718117	0.264853643	**0.70333**	0.711793	0.258569	0.70723	0.709616	0.254155	0.70832687	**-6.98758**
104.6744	-11.1547	138.9076	-7.5196	6.061236	0.833866	0.838602	0.271450586	**0.821315**	0.830251	0.258273	0.824733	0.824862	0.250916	0.825419112	**-7.02553**
104.6835	-11.2003	138.9073	-7.524	6.131076	0.903707	0.942997	0.251155509	**0.93997**	0.939164	0.245263	0.944356	0.933834	0.239231	0.941641744	**-6.97336**
104.7812	-11.3438	138.927	-7.5296	6.373616	1.146247	1.041268	0.235945707	**1.088697**	1.040191	0.22499	1.065671	1.035807	0.220707	1.053165614	**-6.69143**
104.7913	-11.3832	138.9334	-7.5294	6.440011	1.212642	1.138503	0.197435912	**1.18507**	1.134955	0.197475	1.164516	1.131516	0.198633	1.150991564	**-5.86956**
104.7913	-11.3832	138.9334	-7.5294	6.44001	1.21264	1.222748	0.169642848	**1.240126**	1.224471	0.171982	1.238224	1.22233	0.179382	1.233017846	**-4.92158**
104.8196	-11.4652	138.9551	-7.5571	6.531141	1.303772	1.317617	0.145452352	**1.302831**	1.311474	0.157509	1.305921	1.310003	0.170642	1.307905496	**-4.49326**
104.846	-11.5216	138.9801	-7.5818	6.584015	1.356646	1.384948	0.16114336	**1.366676**	1.391736	0.167874	1.377195	1.396611	0.179581	1.38495504	**-4.62297**
104.8732	-11.5784	138.9874	-7.6005	6.650952	1.423583	1.460179	0.187986955	**1.447926**	1.477889	0.196453	1.460426	1.488882	0.204639	1.471318296	**-5.1818**
104.9315	-11.6806	139.0071	-7.6202	6.79516	1.567791	1.569116	0.235560959	**1.548994**	1.581249	0.236715	1.558068	1.593793	0.239922	1.571435785	**-6.00705**
104.9542	-11.7292	139.0396	-7.6376	6.844931	1.617561	1.688544	0.285285038	**1.65053**	1.7005	0.279481	1.671926	1.71455	0.280224	1.689051398	**-7.05694**
104.9943	-11.806	139.0419	-7.6456	6.966633	1.739263	1.819259	0.315852487	**1.788144**	1.837657	0.320871	1.810415	1.85344	0.322845	1.827493777	**-8.30654**
105.0713	-11.9487	139.082	-7.6506	7.202569	1.9752	1.978523	0.360941487	**1.963643**	1.9964	0.367419	1.972603	2.01258	0.368199	1.987067304	**-9.57441**
105.1064	-12.0316	139.1168	-7.6342	7.367135	2.139765	2.17387	0.458459782	**2.137589**	2.178012	0.419862	2.15122	2.192517	0.413986	2.16654548	**-10.7687**
105.1741	-12.091	139.1327	-7.6208	7.49902	2.27165	2.362106	0.462466213	**2.326772**	2.374847	0.453024	2.349422	2.393911	0.458983	2.367092408	**-12.0328**
105.2244	-12.2061	139.1613	-7.5779	7.765803	2.538433	2.566751	0.457843175	**2.559125**	2.597723	0.49783	2.574404	2.621336	0.512916	2.590785837	**-13.4216**
105.3319	-12.3686	139.208	-7.5095	8.162587	2.935217	2.82608	0.56783288	**2.820279**	2.8523	0.569955	2.817629	2.879022	0.581238	2.83845679	**-14.8603**
105.3319	-12.3685	139.208	-7.5095	8.162585	2.935216	3.099661	0.638941665	**3.028378**	3.141304	0.653874	3.081683	3.170744	0.661925	3.117919108	**-16.7677**
105.3943	-12.4689	139.2276	-7.4733	8.399143	3.171774	3.453039	0.774365995	**3.348277**	3.474415	0.755772	3.402391	3.49886	0.750306	3.4408356	**-19.375**
105.5585	-12.6739	139.3203	-7.3157	9.017876	3.790506	3.818677	0.869010867	**3.745679**	3.837143	0.847067	3.776409	3.859163	0.83336	3.808530003	**-22.0617**
105.6393	-12.7827	139.3507	-7.273	9.2822	4.05483	4.178444	0.958947713	**4.160616**	4.224514	0.921308	4.193272	4.248929	0.90038	4.215719586	**-24.4314**
105.7943	-12.9891	139.4269	-7.0753	9.972664	4.745295	4.631518	1.020885112	**4.658554**	4.652946	0.968472	4.646236	4.666495	0.945484	4.651220394	**-26.13**
105.8711	-13.0779	139.4342	-6.9631	10.32527	5.097899	5.100322	0.991900749	**5.098221**	5.096527	0.982305	5.096524	5.100452	0.965496	5.097372332	**-26.7691**
105.9569	-13.1672	139.4849	-6.8435	10.68096	5.453587	5.531196	0.983148732	**5.531876**	5.540879	0.97287	5.545991	5.540194	0.962932	5.546123062	**-26.925**
106.0817	-13.2941	139.5615	-6.5834	11.3341	6.106734	6.019237	0.976032989	**6.0274**	5.992025	0.958249	6.004641	5.978229	0.945356	5.993103095	**-26.8188**
106.1603	-13.3536	139.5962	-6.441	11.68077	6.453401	6.442979	0.974657324	**6.453341**	6.416671	0.926958	6.440095	6.400823	0.911254	6.425799289	**-25.9618**
106.2476	-13.4247	139.6185	-6.3108	12.03399	6.806624	6.81635	0.86831113	**6.856143**	6.816519	0.865052	6.854597	6.803394	0.860032	6.838564979	**-24.7659**
106.3799	-13.4934	139.6532	-5.9958	12.69849	7.471117	7.220407	0.782296324	**7.318643**	7.202426	0.796258	7.259521	7.186697	0.802194	7.228534558	**-23.3982**
106.4111	-13.5211	139.6558	-5.8833	12.93886	7.711493	7.562952	0.737033271	**7.631072**	7.561658	0.743267	7.604396	7.548447	0.749535	7.582955254	**-21.2652**
106.4111	-13.5211	139.6558	-5.8833	12.93886	7.711492	7.918374	0.712265661	**7.897159**	7.905891	0.701218	7.91452	7.89016	0.703884	7.909363556	**-19.5845**
106.4944	-13.5748	139.6688	-5.6046	13.50936	8.281989	8.249382	0.644689038	**8.233221**	8.229854	0.657915	8.22911	8.209768	0.661987	8.223174244	**-18.8286**
106.5461	-13.5903	139.6829	-5.4928	13.73191	8.504544	8.527975	0.673061085	**8.54203**	8.519729	0.636181	8.536892	8.502327	0.623448	8.525023803	**-18.111**
106.6132	-13.6078	139.6959	-5.2558	14.16873	8.941358	8.788569	0.657200128	**8.862966**	8.788197	0.593779	8.832082	8.769601	0.573365	8.808443571	**-17.0052**
106.6459	-13.611	139.7205	-5.149	14.35105	9.123679	9.064268	0.520672893	**9.123884**	9.03387	0.514087	9.091857	9.009802	0.503366	9.061224326	**-15.1668**

106.6957	-13.6015	139.7405	-4.964	14.64864	9.421268	9.264329	0.431389164	**9.347769**	9.242617	0.42348	9.307434	9.217448	0.420649	9.273986691	**-12.7657**
106.7091	-13.5916	139.7381	-4.8877	14.76302	9.535651	9.451222	0.315070696	**9.510346**	9.418678	0.329408	9.475307	9.39064	0.334501	9.443643409	**-10.1794**
106.7291	-13.5774	139.7402	-4.8131	14.86875	9.641384	9.577424	0.246207279	**9.616872**	9.554412	0.247941	9.595928	9.52723	0.25391	9.571316895	**-7.66041**
106.7578	-13.5578	139.7435	-4.7749	14.90979	9.682418	9.680356	0.160640098	**9.694451**	9.653461	0.175068	9.682637	9.626508	0.180582	9.662740115	**-5.48539**
106.76	-13.5551	139.7482	-4.6911	15.04016	9.812793	9.740776	0.121790629	**9.774456**	9.719053	0.118235	9.749234	9.692111	0.117875	9.724494767	**-3.70528**
106.766	-13.5226	139.7458	-4.6535	15.05214	9.824772	9.781049	0.083131358	**9.813103**	9.759219	0.075582	9.788209	9.730357	0.069181	9.757339738	**-1.9707**
106.7821	-13.4718	139.7569	-4.592	15.07158	9.844206	9.800355	0.056818583	**9.81723**	9.776008	0.045928	9.786806	9.745808	0.040134	9.755486098	**0.111218**
106.7821	-13.4717	139.7569	-4.592	15.07157	9.844205	9.809716	0.035575857	**9.806912**	9.772424	0.053679	9.766655	9.740564	0.050754	9.737040404	**1.106742**
106.7863	-13.4377	139.76	-4.5747	15.04494	9.817567	9.794145	0.05339591	**9.791512**	9.748463	0.082381	9.743031	9.714659	0.082155	9.709506129	**1.652057**
106.7811	-13.4094	139.772	-4.5671	15.00389	9.776522	9.745675	0.125828617	**9.734394**	9.708355	0.109535	9.704082	9.669422	0.115373	9.663360822	**2.768718**
106.7714	-13.3893	139.7684	-4.563	14.97532	9.747949	9.684163	0.167859913	**9.66936**	9.650456	0.144067	9.645934	9.608881	0.149618	9.602441699	**3.655147**
106.7635	-13.3578	139.7616	-4.5584	14.93116	9.703794	9.613587	0.191542512	**9.606733**	9.574593	0.18261	9.567898	9.534318	0.183993	9.528408437	**4.441996**
106.7279	-13.2485	139.7717	-4.5717	14.71285	9.48548	9.528915	0.215809187	**9.532345**	9.479778	0.21974	9.471548	9.444462	0.215899	9.439390444	**5.34108**
106.7199	-13.2226	139.7713	-4.5881	14.64099	9.413622	9.414049	0.26938755	**9.411936**	9.37051	0.258739	9.363018	9.338918	0.246278	9.334181966	**6.312509**
106.7168	-13.2021	139.772	-4.6057	14.57754	9.350172	9.285496	0.296807612	**9.275875**	9.249626	0.291449	9.244716	9.218303	0.275832	9.213194459	**7.25925**
106.6906	-13.1487	139.7748	-4.6219	14.45224	9.224866	9.137481	0.311426569	**9.127806**	9.116077	0.313863	9.114042	9.083736	0.305077	9.078173283	**8.101271**
106.6726	-13.0539	139.7624	-4.681	14.19983	8.972457	8.976069	0.38509484	**8.969519**	8.966727	0.331038	8.965272	8.936882	0.333389	8.931590386	**8.794974**
106.646	-13.012	139.7716	-4.7065	14.07545	8.848079	8.824921	0.392302955	**8.823167**	8.80548	0.352255	8.801631	8.779236	0.358279	8.775038969	**9.393085**
106.6404	-12.9582	139.7715	-4.7621	13.89506	8.667692	8.66773	0.366352402	**8.67189**	8.632565	0.378933	8.62593	8.609779	0.381213	8.606531257	**10.11046**
106.5944	-12.8544	139.7676	-4.8394	13.58296	8.355592	8.476605	0.37610558	**8.486893**	8.45025	0.406921	8.443567	8.427108	0.404934	8.423445007	**10.98517**
106.5944	-12.8544	139.7676	-4.8394	13.58296	8.355591	8.292022	0.407911338	**8.283207**	8.26305	0.429041	8.259495	8.231748	0.43106	8.226520149	**11.81549**
106.5629	-12.814	139.7648	-4.8569	13.4772	8.249833	8.08109	0.451841645	**8.065472**	8.060214	0.454949	8.058517	8.025304	0.457857	8.019361019	**12.42955**
106.5191	-12.7129	139.7723	-4.9658	13.11436	7.886994	7.862223	0.489804828	**7.851604**	7.83952	0.482632	7.835342	7.809337	0.483173	7.804498795	**12.89173**
106.487	-12.6619	139.7758	-5.033	12.90774	7.680375	7.658976	0.543228243	**7.659114**	7.60579	0.512137	7.597756	7.584731	0.504186	7.582033156	**13.34794**
106.4342	-12.5539	139.7408	-5.1096	12.59892	7.371554	7.400839	0.58476991	**7.403317**	7.363552	0.538654	7.356519	7.35032	0.519398	7.34892584	**13.98644**
106.3975	-12.4841	139.7473	-5.1742	12.36299	7.135623	7.130178	0.564430834	**7.127036**	7.116547	0.559179	7.114162	7.108155	0.529256	7.106831196	**14.52568**
106.3522	-12.4351	139.7525	-5.2379	12.16023	6.932865	6.85755	0.597853003	**6.850781**	6.868157	0.564395	6.871323	6.861633	0.535943	6.860039381	**14.80751**
106.3039	-12.3033	139.7318	-5.3344	11.776	6.54863	6.587812	0.590645845	**6.587542**	6.613511	0.549989	6.618619	6.61436	0.539	6.613607812	**14.78589**
106.27	-12.2477	139.7346	-5.389	11.58257	6.355205	6.332676	0.581333666	**6.336434**	6.359601	0.534654	6.363367	6.368601	0.536396	6.369670374	**14.63625**
106.1995	-12.1219	139.7032	-5.4843	11.20597	5.978602	6.094543	0.537351495	**6.112879**	6.109636	0.524999	6.109682	6.12558	0.527604	6.12854493	**14.46753**
106.1755	-12.0806	139.6944	-5.5533	11.01958	5.792207	5.859701	0.464146058	**5.876591**	5.867778	0.516564	5.866847	5.884464	0.515525	5.887740569	**14.44826**
106.1535	-12.0182	139.6963	-5.6117	10.81297	5.585599	5.622851	0.47684415	**5.625943**	5.634468	0.506005	5.636205	5.645947	0.505382	5.64776132	**14.39875**
106.1279	-11.9684	139.6646	-5.6339	10.69607	5.468697	5.391101	0.45532186	**5.377284**	5.40779	0.494408	5.413016	5.411964	0.496955	5.412169478	**14.13551**
106.1092	-11.9035	139.6844	-5.6708	10.51634	5.28897	5.169809	0.496743097	**5.157771**	5.17952	0.483362	5.18351	5.183823	0.489783	5.184223813	**13.67674**
106.0147	-11.8029	139.6357	-5.8031	10.11805	4.890681	4.951815	0.512659208	**4.954371**	4.949879	0.478825	4.949005	4.961579	0.481082	4.963786648	**13.22623**
105.9824	-11.7355	139.622	-5.8279	9.960319	4.732949	4.740557	0.512653358	**4.749694**	4.728266	0.472725	4.725486	4.742972	0.471007	4.746275265	**13.05068**
105.9236	-11.6354	139.6114	-5.9031	9.656928	4.429559	4.504374	0.502014435	**4.514987**	4.512691	0.471502	4.512694	4.52694	0.459113	4.529593212	**13.00092**
105.8953	-11.5836	139.6049	-5.9464	9.493617	4.266247	4.268802	0.457393707	**4.269101**	4.305581	0.459171	4.311135	4.315529	0.446952	4.316784758	**12.76851**
105.8604	-11.5307	139.5888	-5.9868	9.334167	4.106797	4.074106	0.438224673	**4.074651**	4.099766	0.442476	4.105959	4.111206	0.435877	4.112452014	**12.25996**
105.8256	-11.4095	139.568	-6.0394	9.04278	3.81541	3.86395	0.42205021	**3.868265**	3.896541	0.420353	3.90079	3.912439	0.426204	3.914574931	**11.87262**
105.7895	-11.3646	139.5427	-6.0987	8.86734	3.639971	3.697136	0.390847716	**3.707998**	3.702861	0.399741	3.703632	3.717823	0.417372	3.720354012	**11.65326**
105.7612	-11.3254	139.5443	-6.1225	8.755179	3.527809	3.510998	0.384858936	**3.513665**	3.518058	0.393308	3.518748	3.524488	0.410119	3.525761312	**11.67556**
105.7057	-11.2376	139.5161	-6.1911	8.489228	3.261859	3.326904	0.359753605	**3.327123**	3.333795	0.391223	3.334116	3.333138	0.406058	3.332929448	**11.56991**
105.7057	-11.2376	139.5161	-6.1911	8.489227	3.261858	3.162975	0.361492721	**3.159225**	3.151263	0.398303	3.150384	3.143321	0.407038	3.142235982	**11.44161**
105.631	-11.1626	139.509	-6.2863	8.190648	2.963278	2.9784	0.404626522	**2.975479**	2.960658	0.406637	2.957785	2.952475	0.413674	2.951203808	**11.46193**
105.6113	-11.1173	139.4904	-6.3284	8.045512	2.818142	2.791123	0.411279875	**2.784813**	2.769616	0.417519	2.766515	2.75871	0.421802	2.757123316	**11.64483**
105.5876	-11.0789	139.4507	-6.3828	7.89528	2.66791	2.59652	0.469567896	**2.590542**	2.574449	0.432515	2.57207	2.562602	0.428752	2.561088114	**11.76211**
105.5265	-10.9926	139.4298	-6.4838	7.575315	2.347945	2.376639	0.466447844	**2.373758**	2.369725	0.448454	2.367705	2.365269	0.43101	2.364812069	**11.77656**
105.4904	-10.9495	139.4052	-6.5181	7.444238	2.216869	2.175836	0.474302168	**2.176369**	2.164054	0.454439	2.162398	2.168237	0.430252	2.169262529	**11.73297**
105.4247	-10.8664	139.3755	-6.6213	7.12701	1.899641	1.955182	0.484852886	**1.960958**	1.960404	0.449282	1.961359	1.970873	0.42693	1.972508461	**11.80524**
105.4017	-10.8245	139.3554	-6.6855	6.950056	1.722686	1.726343	0.470197983	**1.726157**	1.763105	0.429243	1.769053	1.774743	0.42001	1.775965464	**11.79258**
105.3704	-10.7811	139.3452	-6.7388	6.785025	1.557656	1.533819	0.448671112	**1.535781**	1.571282	0.410489	1.578564	1.583733	0.409298	1.585136377	**11.44975**
105.3069	-10.7053	139.3207	-6.8293	6.500933	1.273564	1.347518	0.38384861	**1.35926**	1.381161	0.391275	1.384961	1.398628	0.396786	1.401251135	**11.03311**
105.2747	-10.681	139.3189	-6.9264	6.293408	1.066038	1.18644	0.348493431	**1.209451**	1.199588	0.371801	1.199161	1.218551	0.384688	1.221975721	**10.75652**

105.2634	-10.6627	139.2979	-6.9487	6.227652	1.000282	1.022445	0.323281121	**1.030996**	1.030305	0.361719	1.030636	1.04123	0.374587	1.043394371	**10.71488**
105.2398	-10.646	139.2692	-6.9852	6.140127	0.912757	0.854358	0.303928871	**0.845526**	0.864251	0.35778	0.866664	0.866922	0.36668	0.867173135	**10.57327**
105.2331	-10.6285	139.2324	-7.0553	5.999466	0.772096	0.700721	0.327600889	**0.689943**	0.69912	0.357988	0.700821	0.696759	0.36257	0.696289191	**10.25304**
105.1939	-10.5902	139.2352	-7.1311	5.802092	0.574723	0.547106	0.376249016	**0.541178**	0.529305	0.357497	0.527804	0.530393	0.360797	0.530782934	**9.930375**
105.1597	-10.5514	139.1926	-7.2094	5.608412	0.381043	0.375368	0.407950676	**0.373404**	0.360901	0.359427	0.358411	0.365671	0.357545	0.367003339	**9.826776**
105.153	-10.5244	139.1982	-7.2909	5.42548	0.198111	0.201167	0.40051717	**0.203341**	0.195025	0.366361	0.193818	0.202792	0.350917	0.204545706	**9.747458**
105.1128	-10.4797	139.1667	-7.3697	5.218101	-0.00927	0.016453	0.391380223	**0.020745**	0.032602	0.362382	0.034596	0.042305	0.341963	0.043930447	**9.636916**
105.1109	-10.4573	139.1609	-7.463	5.025484	-0.20189	-0.1545	0.367510505	**-0.14783**	-0.12693	0.346649	-0.12241	-0.11292	0.331306	-0.111056084	**9.299192**
105.0939	-10.4343	139.1541	-7.5019	4.920717	-0.30665	-0.3187	0.344403715	**-0.31561**	-0.27987	0.324564	-0.27349	-0.26187	0.318192	-0.259346075	**8.897399**
105.0748	-10.4133	139.1431	-7.6085	4.706468	-0.5209	-0.45677	0.292504109	**-0.44701**	-0.42708	0.301771	-0.42259	-0.40333	0.301523	-0.399623973	**8.416674**
105.0561	-10.3915	139.1198	-7.6475	4.605424	-0.62195	-0.58524	0.25873845	**-0.57558**	-0.56185	0.27817	-0.5588	-0.53804	0.283367	-0.533895868	**8.056314**
105.0405	-10.3575	139.1113	-7.7006	4.458994	-0.76838	-0.70509	0.245534427	**-0.69712**	-0.68684	0.256883	-0.68419	-0.6657	0.265647	-0.662087894	**7.691522**
105.0405	-10.3575	139.1113	-7.7006	4.458992	-0.76838	-0.82392	0.220575756	**-0.82717**	-0.80071	0.241092	-0.79642	-0.78626	0.248958	-0.783891483	**7.308215**
105.0351	-10.3485	139.1232	-7.7741	4.318807	-0.90856	-0.92114	0.214662681	**-0.92262**	-0.91123	0.228939	-0.9084	-0.89873	0.234715	-0.8967202	**6.769723**
105.0314	-10.3322	139.0864	-7.8394	4.186541	-1.04083	-1.02404	0.219905801	**-1.02274**	-1.01698	0.218791	-1.01601	-1.00498	0.223244	-1.002843838	**6.367418**
105.0265	-10.3167	139.0965	-7.8811	4.088927	-1.13844	-1.11642	0.230197353	**-1.11276**	-1.11737	0.208551	-1.11742	-1.10607	0.213785	-1.103943908	**6.066004**
105.0221	-10.3157	139.0852	-7.9183	4.025898	-1.20147	-1.2207	0.210767056	**-1.22062**	-1.21132	0.204116	-1.2099	-1.20331	0.204041	-1.201765692	**5.869307**
105.0236	-10.2963	139.0753	-7.9837	3.885152	-1.34222	-1.31801	0.199589334	**-1.31581**	-1.30443	0.199073	-1.30253	-1.29532	0.19387	-1.293824408	**5.523523**
105.01	-10.2917	139.0496	-8.0234	3.812304	-1.41507	-1.40324	0.188568334	**-1.39987**	-1.39346	0.191301	-1.39182	-1.38191	0.183395	-1.379898653	**5.164455**
105.0058	-10.2801	139.0703	-8.0599	3.72905	-1.49832	-1.48774	0.182570471	**-1.48483**	-1.4787	0.177833	-1.47707	-1.46349	0.172843	-1.460906911	**4.860495**
105.017	-10.2637	139.0821	-8.098	3.637619	-1.58975	-1.57527	0.168815497	**-1.57442**	-1.55582	0.163759	-1.55253	-1.54054	0.160744	-1.538060273	**4.629202**
105.0109	-10.2585	139.079	-8.1211	3.589972	-1.6374	-1.64655	0.159061656	**-1.64594**	-1.62627	0.148689	-1.6221	-1.61163	0.147434	-1.609342905	**4.276958**
105.0141	-10.2464	139.0715	-8.1649	3.497414	-1.72996	-1.7126	0.141997543	**-1.70941**	-1.69203	0.132813	-1.68849	-1.67615	0.133359	-1.67361446	**3.856293**
105.011	-10.2458	139.0863	-8.2135	3.413155	-1.81421	-1.76881	0.119064479	**-1.76046**	-1.75133	0.116537	-1.74922	-1.73382	0.119478	-1.730747968	**3.428011**
105.0117	-10.2399	139.0722	-8.2245	3.386222	-1.84115	-1.8167	0.101103085	**-1.80901**	-1.80197	0.103099	-1.80019	-1.78562	0.105566	-1.782548752	**3.108047**
105.0148	-10.2345	139.0725	-8.2409	3.349952	-1.87742	-1.86303	0.076569544	**-1.86019**	-1.84608	0.090503	-1.84346	-1.83176	0.091886	-1.82924149	**2.801564**
105.0169	-10.2342	139.0691	-8.2495	3.335567	-1.8918	-1.89932	0.061756187	**-1.89986**	-1.88404	0.078552	-1.88074	-1.87203	0.079595	-1.870107988	**2.45199**
105.0254	-10.2255	139.0714	-8.261	3.302382	-1.92499	-1.92846	0.063018717	**-1.92893**	-1.91774	0.066361	-1.91509	-1.90664	0.069294	-1.904877916	**2.086196**
105.0291	-10.2242	139.0703	-8.2818	3.265683	-1.96169	-1.95541	0.059703912	**-1.95473**	-1.94678	0.054214	-1.94509	-1.93677	0.0606	-1.935054151	**1.810574**
105.038	-10.2045	139.0687	-8.276	3.243366	-1.984	-1.97712	0.053971592	**-1.97508**	-1.97136	0.046925	-1.97044	-1.96307	0.052798	-1.96151336	**1.587553**
105.045	-10.1856	139.0726	-8.2777	3.209163	-2.01821	-1.99974	0.04461172	**-1.99639**	-1.99219	0.042007	-1.99146	-1.98611	0.04559	-1.98489847	**1.403107**
105.0467	-10.1786	139.0726	-8.2777	3.197577	-2.02979	-2.01593	0.03164874	**-2.01229**	-2.01147	0.038989	-2.0111	-2.00554	0.038744	-2.004378423	**1.168797**
105.0532	-10.1521	139.0865	-8.2505	3.197975	-2.02939	-2.03239	0.028535765	**-2.03224**	-2.02818	0.035523	-2.02754	-2.02201	0.032816	-2.020815678	**0.986235**
105.0707	-10.1381	139.1062	-8.2487	3.177289	-2.05008	-2.0446	0.021892403	**-2.0457**	-2.04288	0.030878	-2.04206	-2.03566	0.027185	-2.034354401	**0.812323**
105.0918	-10.122	139.1151	-8.2263	3.189003	-2.03837	-2.06139	0.037683813	**-2.06387**	-2.05313	0.024023	-2.05109	-2.04728	0.022043	-2.046314303	**0.717594**
105.0974	-10.0953	139.1178	-8.2227	3.150494	-2.07688	-2.07053	0.036477636	**-2.07167**	-2.06262	0.017408	-2.06038	-2.05632	0.017158	-2.055471745	**0.549447**
105.1042	-10.0752	139.1261	-8.1981	3.157911	-2.06946	-2.07457	0.032512725	**-2.07799**	-2.06855	0.011355	-2.06601	-2.06278	0.012362	-2.061977587	**0.39035**
105.1203	-10.0344	139.1302	-8.1975	3.091579	-2.13579	-2.07846	0.030671	**-2.06815**	-2.0735	0.006028	-2.07281	-2.06512	0.008834	-2.064604814	**0.157634**
105.1124	-10.0035	139.118	-8.1418	3.133631	-2.09374	-2.08543	0.0250737	**-2.07869**	-2.07284	0.007358	-2.07433	-2.0624	0.014786	-2.066684	**0.124751**
105.1173	-9.9836	139.1145	-8.1009	3.169689	-2.05768	-2.08494	0.025300307	**-2.0738**	-2.06284	0.027957	-2.07279	-2.05193	0.032178	-2.061053867	**-0.33781**
105.1313	-9.95635	139.1329	-8.0851	3.150048	-2.07732	-2.05329	0.093778561	**-2.0803**	-2.03836	0.064107	-2.05841	-2.03191	0.056418	-2.045862233	**-0.9115**
105.1403	-9.9056	139.1364	-8.0405	3.140223	-2.08715	-2.01462	0.108711518	**-2.05927**	-2.01028	0.087619	-2.03207	-2.00455	0.076245	-2.01878195	**-1.62482**
105.1523	-9.89365	139.1593	-8.0198	3.153912	-2.07346	-1.9826	0.114397461	**-2.00166**	-1.97775	0.099461	-1.98709	-1.97245	0.088317	-1.979411978	**-2.3622**
105.3641	-9.51585	139.2408	-7.5154	3.379444	-1.84793	-1.95593	0.115723435	**-1.90666**	-1.94219	0.1038	-1.92588	-1.93642	0.091926	-1.93172669	**-2.86112**
105.3976	-9.4523	139.2614	-7.4628	3.362265	-1.8651	-1.91177	0.120562575	**-1.87159**	-1.90001	0.098162	-1.88126	-1.89803	0.088538	-1.888215107	**-2.61069**
105.4114	-9.42955	139.2526	-7.444	3.357836	-1.86953	-1.86056	0.109263492	**-1.85096**	-1.85615	0.082487	-1.84962	-1.85959	0.078473	-1.852457539	**-2.14545**
105.4314	-9.3998	139.3194	-7.4124	3.356331	-1.87104	-1.81501	0.061911756	**-1.82488**	-1.81955	0.061267	-1.82059	-1.82553	0.064404	-1.821437165	**-1.86122**
105.4691	-9.34725	139.2777	-7.3036	3.45918	-1.76819	-1.79609	0.06990145	**-1.78505**	-1.79505	0.054551	-1.78969	-1.799	0.053495	-1.793255121	**-1.69092**
105.4998	-9.3365	139.286	-7.2708	3.498729	-1.72864	-1.77789	0.065377322	**-1.75222**	-1.7756	0.046367	-1.76304	-1.77855	0.043177	-1.769648453	**-1.4164**
105.518	-9.3041	139.291	-7.2546	3.472706	-1.75466	-1.76124	0.0515215	**-1.74548**	-1.7587	0.034313	-1.74861	-1.76245	0.031768	-1.753805783	**-0.95056**
105.5453	-9.28775	139.2819	-7.2173	3.511897	-1.71547	-1.7426	0.017639933	**-1.73515**	-1.74605	0.018545	-1.74021	-1.75055	0.01964	-1.744410094	**-0.56374**
105.5586	-9.2437	139.2868	-7.1869	3.489668	-1.7377	-1.7387	0.013593171	**-1.73545**	-1.74005	0.007072	-1.7381	-1.74262	0.010093	-1.739517972	**-0.29353**
105.6014	-9.1906	139.2674	-7.1466	3.47439	-1.75298	-1.73784	0.01449969	**-1.73265**	-1.73799	0.004607	-1.73689	-1.73724	0.006941	-1.737375163	**-0.12857**
105.6278	-9.181	139.2523	-7.1322	3.486822	-1.74055	-1.73759	0.014175833	**-1.73637**	-1.73419	0.007457	-1.73735	-1.73191	0.010288	-1.734840279	**-0.15209**

105.661	-9.1684	139.2527	-7.1218	3.486474	-1.7409	-1.73632	0.01667049	**-1.74304**	-1.72907	0.01511	-1.73416	-1.72407	0.019597	-1.729170081	**-0.34021**
105.7121	-9.13385	139.2268	-7.0812	3.504769	-1.7226	-1.72942	0.024258796	**-1.73777**	-1.71767	0.031102	-1.72538	-1.71101	0.033932	-1.719198287	**-0.59831**
105.7501	-9.10765	139.2254	-7.0752	3.474438	-1.75293	-1.70615	0.055682677	**-1.71893**	-1.69863	0.053289	-1.71128	-1.69131	0.051748	-1.702136856	**-1.02369**
105.8027	-9.0982	139.2043	-7.0431	3.520799	-1.70657	-1.67758	0.080763695	**-1.69925**	-1.67136	0.075127	-1.68535	-1.66436	0.069757	-1.675808221	**-1.57972**
105.8475	-9.0694	139.1855	-7.0082	3.537937	-1.68943	-1.63859	0.106782139	**-1.65569**	-1.63629	0.091579	-1.64664	-1.63086	0.085244	-1.639939972	**-2.15209**
105.917	-9.0476	139.1521	-6.9349	3.637298	-1.59007	-1.60221	0.116332628	**-1.59936**	-1.59697	0.099495	-1.599	-1.5911	0.097793	-1.596245608	**-2.62166**
105.977	-9.0312	139.1414	-6.8942	3.686846	-1.54052	-1.56082	0.104742136	**-1.54548**	-1.55067	0.108311	-1.54872	-1.54375	0.109447	-1.54778189	**-2.90782**
106.0389	-9.00485	139.1239	-6.8309	3.759383	-1.46799	-1.49808	0.131090495	**-1.49757**	-1.49353	0.121564	-1.49964	-1.48869	0.122514	-1.496093159	**-3.10132**
106.0389	-9.00485	139.1239	-6.8309	3.759381	-1.46799	-1.4332	0.132980253	**-1.46253**	-1.43208	0.134007	-1.44706	-1.42683	0.137836	-1.438386896	**-3.46238**
106.1046	-8.9831	139.1326	-6.8101	3.764211	-1.46316	-1.3744	0.142705756	**-1.3948**	-1.36479	0.152923	-1.37985	-1.35731	0.157788	-1.370767745	**-4.05715**
106.2024	-8.9404	139.1027	-6.6629	3.959937	-1.26743	-1.29693	0.179850565	**-1.29925**	-1.28688	0.181739	-1.29991	-1.27825	0.182606	-1.29255144	**-4.69298**
106.2645	-8.9199	139.1109	-6.6276	3.992106	-1.23526	-1.20762	0.229200018	**-1.22555**	-1.19751	0.212132	-1.2136	-1.18828	0.208625	-1.203597479	**-5.33724**
106.3196	-8.89255	139.1084	-6.5716	4.048919	-1.17845	-1.1097	0.245282379	**-1.12836**	-1.09615	0.232897	-1.11241	-1.08676	0.233181	-1.101932661	**-6.09989**
106.4164	-8.8448	139.1103	-6.4272	4.229126	-0.99824	-0.99434	0.241213368	**-1.0001**	-0.98269	0.255522	-0.99526	-0.97335	0.258545	-0.987560787	**-6.86231**
106.4681	-8.8163	139.1035	-6.314	4.384541	-0.84283	-0.86239	0.30979612	**-0.872**	-0.85524	0.291302	-0.8699	-0.84818	0.284868	-0.862380638	**-7.51081**
106.53	-8.77695	139.1024	-6.245	4.444827	-0.78254	-0.72816	0.324519286	**-0.75299**	-0.7186	0.312226	-0.73639	-0.71401	0.304556	-0.726718152	**-8.13975**
106.5681	-8.74045	139.0952	-6.1395	4.571782	-0.65559	-0.57571	0.328361629	**-0.60056**	-0.57582	0.321979	-0.586	-0.57395	0.316021	-0.580344313	**-8.78243**
106.6878	-8.6999	139.1124	-5.9295	4.883565	-0.3438	-0.4326	0.331802885	**-0.4071**	-0.43255	0.324844	-0.42367	-0.43039	0.320952	-0.428025359	**-9.13914**
106.7629	-8.67005	139.1156	-5.8784	4.931723	-0.29565	-0.29682	0.330417427	**-0.26907**	-0.28822	0.321467	-0.27444	-0.28287	0.322597	-0.278338266	**-8.98123**
106.8138	-8.6451	139.1403	-5.7509	5.116058	-0.11131	-0.14764	0.30964994	**-0.12892**	-0.13501	0.318601	-0.13202	-0.12886	0.327284	-0.13143951	**-8.81393**
106.8697	-8.60285	139.1582	-5.6468	5.230914	0.003544	0.023383	0.312931052	**0.002821**	0.026673	0.329936	0.009663	0.032337	0.342158	0.0180558	**-8.96972**
106.9113	-8.566	139.1837	-5.5523	5.334991	0.107622	0.175437	0.35985142	**0.138279**	0.1923	0.365032	0.162796	0.201105	0.369972	0.178642077	**-9.63518**
106.9741	-8.542	139.1812	-5.447	5.489079	0.261709	0.371331	0.427537979	**0.319498**	0.373929	0.410662	0.341614	0.380107	0.403173	0.356973777	**-10.6999**
107.0802	-8.4668	139.2255	-5.2192	5.768939	0.541569	0.55746	0.464417937	**0.531198**	0.562196	0.442558	0.542415	0.567226	0.429004	0.552357936	**-11.723**
107.1307	-8.44685	139.2162	-5.104	5.947941	0.720572	0.745124	0.468677871	**0.752295**	0.755792	0.453355	0.757706	0.760481	0.440517	0.75936751	**-12.4206**
107.2488	-8.4056	139.2513	-4.8708	6.302981	1.075612	0.957848	0.469033111	**1.002332**	0.958465	0.448376	0.97857	0.958279	0.438265	0.968821512	**-12.5672**
107.3095	-8.38525	139.2717	-4.7894	6.418958	1.191589	1.165764	0.429967924	**1.188948**	1.158579	0.427791	1.177818	1.155657	0.425179	1.169054284	**-12.014**
107.3772	-8.359	139.293	-4.6975	6.544564	1.317194	1.351903	0.395351889	**1.357994**	1.352876	0.403529	1.362446	1.349728	0.408321	1.35910229	**-11.4029**
107.4625	-8.3284	139.3463	-4.5129	6.824062	1.596693	1.562239	0.395152003	**1.556993**	1.546287	0.391985	1.547386	1.53939	0.395642	1.543612041	**-11.0706**
107.5109	-8.2971	139.3455	-4.4196	6.94449	1.717121	1.721855	0.391468935	**1.720292**	1.724384	0.38683	1.723255	1.72169	0.388087	1.723303665	**-10.7815**
107.5468	-8.28355	139.366	-4.3361	7.07191	1.84454	1.894309	0.384778407	**1.891279**	1.899092	0.380821	1.900913	1.900682	0.384359	1.902014906	**-10.7227**
107.6248	-8.2811	139.4121	-4.1412	7.420296	2.192927	2.070668	0.358171492	**2.106169**	2.077543	0.377668	2.085341	2.081398	0.386498	2.081287887	**-10.7564**
107.6248	-8.2811	139.4121	-4.1412	7.420294	2.192925	2.248299	0.390776855	**2.249017**	2.259448	0.391554	2.25467	2.266738	0.39862	2.258930495	**-10.6586**
107.6691	-8.28475	139.3881	-4.0378	7.626132	2.398762	2.437339	0.410560402	**2.411897**	2.452688	0.414251	2.430766	2.460635	0.419744	2.443175347	**-11.0547**
107.7191	-8.2842	139.3864	-3.9581	7.779077	2.551708	2.657605	0.451120458	**2.607154**	2.658699	0.445895	2.627456	2.663998	0.447308	2.641854991	**-11.9208**
107.7878	-8.27715	139.4245	-3.7929	8.067479	2.84011	2.847061	0.499347021	**2.830329**	2.866942	0.483637	2.844762	2.874937	0.476175	2.856865809	**-12.9006**
107.8263	-8.28015	139.437	-3.6868	8.267768	3.040399	3.08469	0.530963266	**3.072968**	3.089857	0.510233	3.080539	3.094607	0.496589	3.085982862	**-13.747**
107.9116	-8.2911	139.4626	-3.5117	8.613776	3.386407	3.314281	0.532397301	**3.333356**	3.319234	0.51554	3.324452	3.319204	0.501811	3.321838902	**-14.1514**
107.9315	-8.2805	139.4572	-3.4302	8.74649	3.519121	3.559136	0.517149635	**3.563871**	3.549027	0.503597	3.561916	3.54271	0.490655	3.55524676	**-14.0045**
107.9956	-8.27575	139.4841	-3.2413	9.083695	3.856325	3.781402	0.490261731	**3.809421**	3.769416	0.473312	3.79236	3.758335	0.463731	3.779491446	**-13.4547**
108.0289	-8.27035	139.4827	-3.1572	9.233271	4.005902	3.987781	0.426230217	**4.017536**	3.972561	0.427528	4.002945	3.960049	0.425265	3.987244003	**-12.4652**
108.0664	-8.2787	139.5319	-3.0171	9.493058	4.265689	4.162073	0.38697355	**4.215707**	4.156357	0.380947	4.191995	4.145653	0.383054	4.174458375	**-11.2329**
108.076	-8.27485	139.5384	-2.9402	9.623339	4.395969	4.337155	0.318845136	**4.373048**	4.326447	0.335396	4.354139	4.316111	0.343437	4.339642423	**-9.91104**
108.0911	-8.26445	139.5562	-2.879	9.712423	4.485054	4.491317	0.308325116	**4.494985**	4.482099	0.307093	4.492537	4.472213	0.312656	4.485976016	**-8.78002**
108.0964	-8.2588	139.5771	-2.802	9.833821	4.606451	4.636241	0.279175489	**4.619931**	4.623897	0.285213	4.623678	4.614888	0.289869	4.621695627	**-8.14318**
108.1107	-8.2626	139.5864	-2.7284	9.972062	4.744692	4.753915	0.270417782	**4.754498**	4.751193	0.271172	4.755124	4.745627	0.27325	4.752280006	**-7.83506**
108.1286	-8.25625	139.6007	-2.6146	10.16283	4.935463	4.869363	0.264575495	**4.898988**	4.870785	0.261015	4.885071	4.867747	0.259819	4.87781757	**-7.53225**
108.1381	-8.25445	139.632	-2.5607	10.24774	5.020369	4.99621	0.262460115	**5.010122**	4.989538	0.250429	5.001673	4.984166	0.245877	4.994854565	**-7.02222**
108.1423	-8.2387	139.6255	-2.5077	10.31678	5.089408	5.108362	0.234385955	**5.106778**	5.100188	0.230201	5.107164	5.093121	0.227833	5.102925994	**-6.48429**
108.1463	-8.23115	139.628	-2.4353	10.43147	5.204102	5.206973	0.198312894	**5.210189**	5.199979	0.205446	5.208984	5.192756	0.206929	5.203860597	**-6.05608**
108.1637	-8.20095	139.6401	-2.3101	10.60035	5.372985	5.290913	0.188338359	**5.326259**	5.288428	0.186686	5.307467	5.282705	0.186757	5.297112674	**-5.59512**
108.1631	-8.1945	139.6577	-2.2897	10.61889	5.391517	5.37284	0.175320337	**5.39448**	5.369728	0.168299	5.386364	5.364133	0.167021	5.378108269	**-4.85974**
108.1719	-8.1832	139.6945	-2.2484	10.66234	5.43497	5.451936	0.149067602	**5.453038**	5.444011	0.1462	5.452568	5.437353	0.146703	5.447936352	**-4.18968**
108.1642	-8.1624	139.6816	-2.1784	10.75041	5.523042	5.514647	0.11612689	**5.518129**	5.508276	0.123379	5.514716	5.501639	0.127262	5.510278808	**-3.74055**

108.182	-8.1336	139.6786	-2.1132	10.82122	5.593854	5.562971	0.117722412	**5.579221**	5.561549	0.111638	5.571666	5.556988	0.112085	5.566004638	**-3.34355**
108.1896	-8.10775	139.6831	-2.0599	10.87045	5.643082	5.610695	0.103485643	**5.626764**	5.609073	0.098724	5.619703	5.605592	0.098737	5.614354207	**-2.90097**
108.1896	-8.10775	139.6831	-2.0599	10.87045	5.643081	5.656165	0.080856818	**5.660044**	5.65214	0.083964	5.658993	5.64909	0.086385	5.655750207	**-2.48376**
108.1857	-8.08695	139.7001	-1.9962	10.93862	5.711251	5.69168	0.065843901	**5.69917**	5.690494	0.073172	5.694909	5.688246	0.076927	5.69238836	**-2.19829**
108.1904	-8.07075	139.6956	-1.9736	10.95296	5.725588	5.728379	0.073392223	**5.727149**	5.726516	0.071306	5.726585	5.723851	0.071461	5.725647914	**-1.99557**
108.185	-8.05865	139.7026	-1.9433	10.98062	5.753254	5.759474	0.077238262	**5.754506**	5.75908	0.070199	5.757057	5.755554	0.066618	5.757019086	**-1.88227**
108.1921	-8.0513	139.7079	-1.9258	10.99902	5.771648	5.791789	0.067077536	**5.786608**	5.78787	0.063851	5.788808	5.782593	0.058852	5.78694605	**-1.79562**
108.1823	-8.0283	139.6927	-1.8587	11.07812	5.850752	5.814885	0.062395792	**5.831375**	5.809884	0.053974	5.820904	5.803641	0.047522	5.813304025	**-1.58148**
108.1837	-8.008	139.6976	-1.832	11.08811	5.860741	5.835934	0.051076488	**5.854709**	5.826676	0.040562	5.841621	5.819066	0.033919	5.830826807	**-1.05137**
108.1798	-7.9966	139.7122	-1.8121	11.09666	5.869287	5.850158	0.035791	**5.861574**	5.838082	0.025203	5.848267	5.828421	0.020237	5.836193242	**-0.32199**
108.193	-7.96555	139.715	-1.781	11.1003	5.872927	5.856754	0.019422115	**5.85327**	5.841873	0.016749	5.842248	5.830861	0.015023	5.83119635	**0.299814**
108.193	-7.96555	139.715	-1.781	11.1003	5.872926	5.847855	0.032500287	**5.844692**	5.836232	0.025325	5.834558	5.825603	0.023267	5.824112011	**0.42506**
108.1885	-7.9436	139.7214	-1.7684	11.08019	5.852825	5.83611	0.04084923	**5.834347**	5.823983	0.034111	5.822542	5.813668	0.03305	5.812098197	**0.720829**
108.1935	-7.91355	139.7221	-1.7592	11.04519	5.817821	5.814429	0.057278966	**5.81314**	5.807071	0.041017	5.805886	5.796592	0.041893	5.794965909	**1.027937**
108.1718	-7.8853	139.7185	-1.7442	11.01582	5.788455	5.792227	0.060834603	**5.791894**	5.785505	0.051119	5.7841	5.776026	0.050247	5.774587821	**1.222685**
108.1565	-7.87545	139.7228	-1.7362	11.0059	5.77853	5.768833	0.055916651	**5.768966**	5.759912	0.060529	5.758079	5.751538	0.058121	5.750318849	**1.456138**
108.1474	-7.8498	139.7123	-1.7457	10.94489	5.717516	5.74075	0.056067458	**5.743186**	5.730489	0.067922	5.728731	5.722313	0.067192	5.720922286	**1.763794**
108.1474	-7.8498	139.7123	-1.7457	10.94488	5.717514	5.705776	0.073595833	**5.702313**	5.699115	0.073846	5.698287	5.687898	0.078067	5.6858409	**2.104883**
108.1442	-7.84565	139.7123	-1.7457	10.93654	5.709172	5.670122	0.086236396	**5.66554**	5.663658	0.081104	5.66314	5.648934	0.089307	5.646496324	**2.360675**
108.1363	-7.82145	139.7192	-1.7489	10.88361	5.656243	5.631024	0.090814586	**5.628387**	5.620198	0.0955	5.61797	5.605527	0.10055	5.603364143	**2.587931**
108.1212	-7.80035	139.7045	-1.7753	10.80037	5.573004	5.591834	0.105304938	**5.593521**	5.569428	0.112224	5.564982	5.55717	0.11215	5.555491965	**2.872331**
108.1065	-7.78315	139.7003	-1.7756	10.76624	5.538873	5.542796	0.116369002	**5.543694**	5.515306	0.127738	5.511347	5.502502	0.124487	5.500682542	**3.288565**
108.103	-7.76835	139.7054	-1.7786	10.73222	5.504846	5.471188	0.147093855	**5.464746**	5.456067	0.141829	5.454232	5.441299	0.13703	5.438841996	**3.710433**
108.0873	-7.7494	139.705	-1.792	10.67056	5.443187	5.397056	0.167618009	**5.387792**	5.390458	0.154492	5.390231	5.375113	0.148855	5.372478864	**3.981788**
108.08	-7.7304	139.7136	-1.8094	10.60162	5.374246	5.327619	0.182589332	**5.323462**	5.316707	0.16431	5.315611	5.305026	0.159664	5.303110123	**4.162124**
108.0366	-7.69395	139.7101	-1.8606	10.43529	5.207917	5.246883	0.197914054	**5.250871**	5.237131	0.170816	5.234722	5.23012	0.169434	5.229019116	**4.44546**
108.0222	-7.6806	139.7143	-1.8842	10.36469	5.137317	5.163466	0.194085688	**5.169119**	5.156737	0.178108	5.154662	5.149716	0.17865	5.148571476	**4.826858**
107.998	-7.66165	139.6963	-1.8929	10.31432	5.086949	5.075755	0.185133022	**5.077264**	5.074964	0.185591	5.074373	5.064188	0.18741	5.062327408	**5.174644**
107.941	-7.64395	139.6821	-1.9322	10.20109	4.973723	4.986678	0.166664313	**4.98666**	4.98731	0.193398	4.987006	4.975166	0.195886	4.97307033	**5.355425**
107.9296	-7.6373	139.6849	-1.9532	10.14829	4.920924	4.903939	0.181620397	**4.901992**	4.893315	0.203576	4.891405	4.882661	0.205544	4.880964177	**5.526369**
107.8935	-7.60765	139.6786	-1.9707	10.05658	4.829212	4.818146	0.194397001	**4.815383**	4.79488	0.214296	4.791537	4.785053	0.216774	4.783514625	**5.846973**
107.8446	-7.58605	139.6497	-1.9905	9.978077	4.750707	4.715387	0.217382224	**4.70988**	4.694937	0.223585	4.692459	4.680714	0.229695	4.678399291	**6.30692**
107.7877	-7.5538	139.6729	-2.0141	9.856107	4.628738	4.601066	0.264251495	**4.592907**	4.588545	0.238339	4.587184	4.570546	0.242865	4.567517241	**6.652923**
107.7648	-7.53735	139.669	-2.0471	9.764139	4.536769	4.486142	0.276604326	**4.48007**	4.473589	0.25541	4.471403	4.456484	0.254283	4.453926462	**6.815447**
107.7192	-7.50375	139.6596	-2.1043	9.595005	4.367635	4.375473	0.271392051	**4.377668**	4.348513	0.273845	4.344	4.33881	0.263805	4.337694747	**6.973903**
107.6298	-7.46205	139.6394	-2.1624	9.400848	4.173479	4.23638	0.295464053	**4.241917**	4.219824	0.287068	4.215836	4.215447	0.272627	4.214972521	**7.363334**
107.5928	-7.4452	139.6491	-2.1706	9.343824	4.116454	4.100924	0.302863277	**4.097294**	4.093225	0.290502	4.092968	4.086925	0.28013	4.085686171	**7.757181**
107.5549	-7.43305	139.6352	-2.1901	9.281894	4.054525	3.948456	0.31527284	**3.939855**	3.964005	0.290925	3.967823				
107.4268	-7.3675	139.6588	-2.2599	9.004427	3.777057	3.809286	0.314410419	**3.809057**	3.826605	0.290117	3.828917				
107.3997	-7.34795	139.6488	-2.2933	8.907921	3.680552	3.697854	0.301796531	**3.706713**	3.689514	0.287881	3.68753				
107.2807	-7.2969	139.6553	-2.3447	8.696857	3.469487	3.561185	0.297221977	**3.575528**							
107.2186	-7.2763	139.6523	-2.3591	8.620821	3.393451	3.416099	0.262064565	**3.415871**							
107.2186	-7.2763	139.6523	-2.3591	8.62082	3.39345	3.288719	0.27381294	**3.282281**							
107.1155	-7.235	139.656	-2.4373	8.38714	3.15977										
106.9746	-7.19465	139.6311	-2.4502	8.266294	3.038925										
106.8804	-7.1794	139.618	-2.5127	8.112766	2.885397										

B.4

Sample worksheet of calculated JRCM output for one trial of task in mockup across all subjects

Ergonomics Result	MM	MSF	ATV	MLV
(Dynamic Mockup, trial 1)				
0.726880159	0	11.30733	12.52201	27.53222
0.891409349	0	4.230282	4.358094	14.00923
0.907229857	0	7.414025	4.131402	7.762026
0.920776285	0	5.071328	4.677334	3.342073
0.877744601	0	26.11513	2.225675	9.185775
0.89825165	0	13.82321	3.662666	7.83793
0.897769915	0	18.1799	3.71426	5.476231
0.921630276	0	4.107003	3.698304	5.209915
0.901086365	0	16.40585	3.37096	6.025013
0.917144322	0	3.509168	4.958095	5.089119
0.927172855	0	7.380615	2.060249	3.962813
0.900965213	0	9.433332	4.891641	7.359662
0.894147914	0	2.923105	3.559314	15.2942
0.908454519	0	16.53611	3.56643	3.244907
0.790995087	0	26.30786	2.221451	26.87223
0.923813046	0	5.752511	3.352294	4.031676
0.899042642	0	16.33075	2.937305	7.4327
0.92406511	0	6.189175	2.878002	4.493115
0.870525224	0	13.95616	8.620071	6.928938
0.87035871	0	17.89237	3.55767	13.36113
0.914823836	0	5.463843	4.981333	4.801442
0.923672923	0	12.63903	2.032929	2.496679
0.883999318	0	20.24571	2.93557	9.587663
0.89587971	0	17.38355	3.344454	7.112722
0.891811411	0	32.31487	0.961593	4.046297
0.914658187	0	8.263586	4.756665	3.685716
0.911129031	0	7.018896	5.219637	4.8257
0.921744065	0	4.105777	4.458766	3.878244
0.852318022	0	13.96588	3.998466	18.9966
0.924154492	0	5.234219	4.355849	2.484112
0.933319173	0	4.222976	2.307614	2.665174
0.926280463	0	7.268895	2.168892	4.205846
0.919277437	0	5.686193	3.138215	6.174311
0.901672682	0	7.601629	6.213606	5.916327
0.908373278	0	18.4921	2.32144	4.294934
0.91415397	0	9.81723	3.859744	4.521316

B.5

Sample worksheet of calculated JRCM output for one trial of task in VE across all subjects

Ergonomics Result (Dynamic VE, trial 1)	MM	MSF	ATV	MLV
0.75921851	0	23.3065	5.042662	28.82966
0.822366988	0	32.22447	4.23291	14.57878
0.830560377	0	38.46728	3.796878	10.26225
0.506436216	0	40.58601	7.286233	46.61315
0.778286087	0	30.74177	5.566121	20.83125
0.856144655	0	40.30795	1.130693	8.36771
0.763694484	0	61.57074	1.210896	13.37995
0.850310382	0	37.81763	2.180182	9.267191
0.819778102	0	49.15501	2.526119	8.55449
0.89631523	0	23.19454	1.641987	6.639198
0.894543197	0	26.15643	1.289858	6.116063
0.927269724	0	5.939816	1.996572	4.831279
0.758895719	0	52.69541	1.879532	17.91126
0.838362558	0	49.84162	1.729106	5.877704
0.87810581	0	35.29496	1.855438	4.619595
0.861626495	0	36.0002	2.74144	6.775078
0.812088372	0	48.91726	2.443562	10.24889
0.919486856	0	7.077284	0.997488	8.95034
0.892057849	0	29.13573	1.070772	5.556464
0.900529267	0	12.74449	4.797327	5.815388
0.821335949	0	33.50435	6.937633	9.480343
0.756337886	0	49.94106	2.367428	19.00166
0.905618977	0	16.59752	2.440552	6.052703
0.874177029	0	33.3255	2.396623	5.80247
0.852544888	0	48.38255	1.234885	4.508862
0.92529007	0	9.850469	1.855689	3.702759
0.897319979	0	26.04646	1.454779	5.070396
0.867965666	0	43.01083	1.233035	3.929945
0.856364154	0	38.69087	1.259448	8.998386
0.796809192	0	41.21832	2.797307	16.62578
0.864015473	0	42.69605	1.936557	3.858318
0.854727039	0	36.59514	2.716001	8.062598
0.926230711	0	5.791369	2.411509	4.635826
0.85460414	0	35.41141	4.06814	6.456581
0.824728506	0	44.45249	1.599832	11.79562
0.891286397	0	21.14345	3.097325	6.784589