Evaluation and Design of a Hospital Bed to be Manufactured and Used in China

A Major Qualifying Project Report

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1 Introduction

Hospitals, rehabilitation homes, nursing homes and retirement homes around the world are dependant upon a quality medical staff to maximize safety of individuals. Staff professionalism, facility quality and the condition of equipment are all key components in medical care which must be taken into account when designing hospitals. Particularly, hospital beds are of recent concern around the world. In the United States, there have been a number of FDA regulations adjusted in recent years while all around Europe recent modifications to reduce the risk of patient entrapment were introduced. In areas such as Africa, Eastern Europe, Asia and other developing nations there is a particular need for improving and modernizing hospital beds.

Hospitals in China have begun to utilize the benefits of a technologically advanced bed. These beds however, are being imported from the leading technological nations including Japan and the United States for an exorbitant price. This increase in bed cost is then passed down to the patients further increasing the cost for quality healthcare and thus resulting in only the upper echelon of Chinese citizens being able to utilize technologically advanced hospital beds and hospital care. The nation’s hospitals are in need of a modern hospital bed that can be produced at a moderate cost within China.

Recently, Chinese engineers and machinists have worked together to furnish the hospitals with modern beds. Their intentions have been quite good and the accommodations made on the beds are on par with beds produced leading manufacturers in the United States, France and Japan. While the additional features of the beds are desirable, the quality and reliability of the Chinese beds conversely are quite questionable. Because engineers have not been able to manufacture and market safe and reliable hospital beds internally, even the neediest of hospitals in China have turned away their native models.

The domestic manufacturing of modern hospital beds in China will allow the nation's hospitals to purchase substantially more modern economical hospital beds. Savings will then be passed on to the citizens and modern hospital care will then be available to a much greater percentage of the Chinese population. The savings on hospital beds will not only allow for more patients to be serviced in the Chinese hospitals, it will also allow the facilities to gear their focus toward other research and pressing accommodations.

Our plan is to research existing models of both Chinese and American brand hospital beds and to analyze the components and functions of each. We will also survey a number of nurses and patients in both the United States and China to determine additional features that could be useful in a modern hospital bed and then begin the design process. Ultimately, we hope to design and manufacture a reliable, reproducible and marketable bed for the People's Republic of China.

2 Background

Hospital beds are manufactured around the world, with each nation providing its own unique qualities and traits to the hospital beds. Our research brought us mostly to American and Chinese manufactured beds solely because of a written language barrier. In researching the beds, we investigated two main types: medical and surgical hospital beds as well as intensive care unit beds.

2.1 American Hospital Beds

The two largest producers of medical beds currently in operation within the United States, Stryker Medical headquartered in Portage, Michigan and Hill-Rom located in Batesville, Indiana, are responsible for the majority of medical beds provided to American hospitals. Two of the most commonly used types of beds are manufactured by these two industries; the most technologically advanced as well as the most costly of these beds are those produced specifically for use in intensive care units, where the most attentive medical care is provided. The second type of bed produced is a Medical/Surgical bed or a Med/Surg bed for short. Med/Surg beds are beds commonly found in hospitals and nursing homes for most rehabilitation purposes. These are beds for patients who require standard medical care and are less sophisticated and less expensive then the beds used in the ICU. These beds come in models powered electrically, manually or a combination of the two. Both ICU and Med/Surg beds share the common bond of serving a purpose to be patient-friendly and user-friendly to accommodate the sick, injured and hospital staff.

2.1.1 Intensive Care Unit Beds

Intensive Care Unit beds are designed upon effective treatment of the patient by both the medical and nursing staffs. Intensive Care Unit beds, or ICU for short, are designed for their functions and abilities as much as they are for patient satisfaction. Patients who will be placed into these beds have serious medical conditions and so ICU beds are designed to give the medical staff a practical and safe working area. Many of the ICU beds are also equipped with emergency releases which convert the bed into immediate CPR mode incase complications from the treatment arise and the patient needs to be revived.

Stryker Medical has been producing beds for intensive care units for over sixty years. Stryker's first major design was known as the Wedge Turning Frame and was developed in 1939. This bed allowed nurses to easily turn their patients and help elevate bed sores caused by long periods of immobility. Stryker continues to design beds based on ease of use to allow nurses to focus less on the beds and more on patient care. The current design by Stryker for Intensive Care Units is the Epic II.

The Epic II is Stryker Medical's most technologically advanced hospital bed.

Figure 1: Stryker Medicals Epic II ICU Bed

Advanced features of this bed include "Zoom" technology which is a bed frame that is motor driven to alleviate stress caused to a nurse's back by the constant pushing and pulling of the bed during patient transport. The Epic II also features a built in electronic scale for accurate weighing of a patient no matter what posture the patient may be in. The bed is also radiolucent to allow for X-rays to be taken while the patient is still in the bed. The Epic II posture controls feature a backrest that can rotate from 0^o to 90^o. The knee gatch, or knee elevation, is from 0^o to 30^o and the trend, or lower leg elevation, can rotate from -12^o to 12^o. These controls are all electronic and are powered by 115 volts alternating current. This bed also features manual release controls for all the variable posture adjustments in case an emergency with the patient occurs. The bed has an overall length of 91 inches, an overall width of 42.5 inches, as well as a variable height between 18 inches and 32.5 inches. This bed can support a total patient weight of 500 pounds. The Epic II has many features which make it Stryker Medicals most advanced Intensive Care bed.

In competition with Stryker's Epic II ICU bed is the Hill-Rom TotalCare bed. The TotalCare bed was developed "in conjunction with leading multi-disciplined healthcare professionals" and features a frame and mattress setting which reduces the back-related injuries and pressure sores associated with patient repositioning, transfers and long term stays. The TotalCare bed has easy to use Point-of-Care controls so the patient can adjust himself into any desirable position all the way to an upright chair position. To further support the patient in a correct sitting posture, the bed advantageously uses the Shearless Pivot Patient Position Mechanism which combines the frame, surface and patient to minimize the patient's migration toward the foot end of the bed. Additionally, there is a retractable foot mechanism which can be placed snug against a patient's feet to reduce the need for additional foot support devices.

Figure 2: Hill-Rom TotalCare ICU Bed

The TotalCare ICU bed provides not only stability and easy to use controls for the patient but is also built to satisfy the needs of patient caregivers. The bed reduces the amount of stress on the caregivers' backs when transferring patients from the bed. The bed provides other capabilities such as an overriding feature for CPR which, by the press of a button, overrides all manual and automatic controls to immediately put the bed into a position convenient for resuscitation in case of emergency. Other support for the caregiver includes a line-of-sight angle indicator to provide the caregiver with the proper head and Trendelenburg angle articulation, side rail controls located just out of the patients reach on the outside of the rails which can be activated only by the system's Enable Command which ensures patient safety from the mechanism and a Graphical Caregiver Interface that records the weight of the patient, includes patient lighting and preset bed positioning. All in all, the TotalCare ICU bed is the ideal bed for any patient in any hospital, but is proven to be an irrational choice for Chinese bed systems as result of their monetary and spatial magnitude.

2.1.2 Medical / Surgical Beds

Medical / Surgical beds are the predominant bed style utilized for patient care in the United States. These beds are designed more for patient comfort and some sacrifice in medical practicability is acceptable. Patients assigned to these beds are generally in a stable medical condition and will have an extended hospital visit. Patients assigned to Med/Surg beds will generally be visited less by the nursing staff and have significantly more freedom then patients assigned to the ICU. Med/Surg beds are designed around the patient and less around the convenience of the medical and nursing staff.

The Hill-Rom VersaCare is the company's premier medical surgical bed with a number of unique components. Most critically, engineers designed the bed to have minimized siderail gaps to reduce patient entrapment, an important feature and topic of heavy legal issue recently in the United States. In fact, the FDA recently released a bill to ensure that all beds have meet stricter standards to reduce patient entrapment.

Additional components of the VersaCare bed include a height of only 18” from the top portion of the mattress to the floor to minimize the risk and impact of patient falls from the bed. Lastly, the “easy grip” bedrails not only reduce patient entrapment occurrences but they are designed to allow patients to easily grasp hold of the rails for egression from their beds.

Figure 3: Hill-Rom VersaCare Med-Surg Bed

In order to assist nurses and reduce their risk of injury, as well as cut down the time it takes for nurses to care for their patients, the VersaCare bed provides to important components: a headboard fixed at a constant height and a “flex-a-foot” feature on the bed. The fixed height of the headboard has been designed based upon ergonomic studies and has been found to reduce the force required to move the bed. Likewise, the flex-a-foot feature reduces patient migration down the bed, thus cutting back on the number of times that nurses have to readjust their patient in the bed. A sheet with all technical specifications for the VersaCare system can be found in **Appendix A**.

The CareAssist bed manufactured by Hill-Rom is the company's mid-class bed. The CareAssist bed utilizes a number of mechanical concepts to aid nurses in their daily tasks but still requires quite a bit of manual assistance. The bed features a non-moving headboard like that of the VersaCare bed, a nightlight to assist patient in egress from bed during nighttime hours, dropdown side rails for more mobile patients and four dual-locking casters to ensure that the bed is locked securely in place as required. The CareAssist bed utilized combinatory automatic and manual components to make it a safe and reliable bed affordable by most middle-class Americans.

Figure 4: Hill-Rom's Care Assist Bed, the middle class alternative

Other features of the CareAssist bed include a built-in bed extender which adjusts the footboard for nurses to appropriately adjust the beds to the specific height of patients, a patient pendant which allows the patient to adjust the bed to his desiring and an attached dining chair position so that the patient can easily adjust from a recovery to eating position by the touch of a button. Lastly, 6" Polyurethane Casters reduce the vibration and shaking of the bed as compared to other similar models. Additional technical data about the Hill-Rom bed may be found in Appendix A: Existing American Bed Models.

Hill Rom's Century+ bed is the company's most economical motorized bed and one that would perhaps best fit as an introductory style bed into the Chinese manufacturing industry. The bed is manufactured to the International Standards Organization or ISO9001 standards and has side rails with embedded controls to have the dual performance of improving caregiver efficiency and reducing entrapment risks. The Century+ Bed comes in four standard models; the CP100, CP200, CP300 and CP400 with the CP400 being the most reliable and accommodating of the packages. A comparative chart of the features in each model and an image of the Hill-Rom Century bed are in Figure 5 and Figure 6 respectively below.

Century$_{TM}$$^{+}$ Bed Value Package Configurations

Model	Dust Cover	Auto Contour	5 UBS (5″ urethane casters with central brake and steer)	5STL (5″ santoprene total lock high mobility)	4SBS (4″ santoprene with central brake brake and steer)	Night Light	CPR
CP 400	X	X	X			X	X
CP 300		X		X			X
CP 200					X		
CP 100				X			

Figure 5: Century+ Bed model comparative chart

Figure 6: Hill-Rom's Century+ Bed, the most economical automatic bed by Hill-Rom

Stryker Medical currently has three different beds available for purchase that are categorized as Med/Surg. The first bed is named the GoBed II. The major features of this bed are its attention to patient comfort and mobility. The GoBed II has an overall length of 94.25 inches, an overall width of 40" and a variable height between 14.5 inches and 29 inches. The lower bed height allows for the patient to enter and exit the bed very easily and without damaging any medical procedure that they have undergone. The backrest of the GoBed II can be positioned anywhere from 0^o to 60^o. The knee gatch can rotate from 0^o to 28^o and the trend can be positioned from -14^o to 14^o. The litter adjustments on the GoBed II are controlled by four independent motors and are powered by 120 volts alternating current at four amperes. All of these design features are with the consideration of patient comfort and convenience.

Figure 7: Stryker Medical GoBed II Med/Surg Bed

There are also many functions of the GoBed II that have been designed with the medical staff's interest in mind. These beds incorporate eight separate poles to be used for IV medicine and fluid bags or for a traction setup to help support proper bone healing. There are also four hooks below the bed to drain and store medical and bodily waste. There are two separate bed controls for the nurse, one on the side rail and one at the foot of the bed. The GoBed also features one handed side rail releases to allow a nurse to drop the side rail at the same time they are helping the patient. The bed also incorporates a drop down fifth wheel to aide in mobility when the bed must be moved. The GoBed II is Stryker Medicals most advanced but almost most expensive Med/Surg bed.

The second Stryker Med/Surg bed design is the Secure II. This bed is designed for patients who are very mobile and require very little medical attention. The Secure II bed is 93 inches long, has a width of 42.5 inches, and a variable height of 16 inches to 30 inches. The overall weight capacity for this bed is 500 pounds. Design functions for the patient include intermediate side rail positioning to help with patient entry and exit. The bed also has a backrest that can be positioned between 0^{o} and 60^{o}. The knee gatch on the Secure II bed can be positioned from 0^{o} to 40^{o}, and the trend can rotate between -12^{o} and 12^{o}. These features are controlled by four independent electronic motors operating at 115 volts alternating current and at seven amperes. These features were all designed with patient convenience and comfort in mind.

Figure 8: Stryker Medical Secure II Med/Serg Bed

The Secure II is designed for patients who require minimal medical supervision and care. It is this factor that influenced the medical functions of this particular bed. There are some important medical functions for this bed however. The Secure II features a removable headboard so CPR may be administered to the patient in the event of an emergency. The bed also features four IV and fluid bag hooks as well as four waste hooks. The Secure II is a bed designed primarily with the concerns of the patient in mind.

Stryker Medical also produces a Long Term Care (LTC) Med/Surg bed. This bed is designed for patients who require long term medical care. These may be elderly patients in a nursing home or patients with debilitating illnesses who require around the clock care. These beds are designed with comfort and durability in mind as patients are generally fragile and confined mainly to their beds. The LTC bed features a drop down caster system to make the bed mobile when needed but extremely stable when not in transport.

Figure 9: Stryker Medical LTC Med/Surg Bed

The LTC bed has an overall length of 87 inches and an overall width of 42 inches. The height of the bed can be adjusted between 12 and 28 inches. The bed is designed to support a maximum weight of 350 pounds. The backrest of the LTC bed can be rotated between 0o and 60o. The knee gatch of this bed can be adjusted from 0^{o} to 30^{o}. The backrest, gatch, and height adjustments are all controlled by 3 independent electric motors that run on 120 volts alternating current and at seven amperes. The controls for the motors are at the foot of the bed and are controlled by the nurse. The LTC bed also features four IV hooks if medicine should become necessary. The LTC bed is designed to look like and feel like a normal bed but function as a medical bed if necessary. It is designed primarily for patient comfort and secondly for patient care. The LTC bed is as the name suggest for patients who require long term medical attention.

2.2 Chinese Hospital Beds

Hospital beds that are produced in China currently are less technologically advanced then the beds that are produced within the United States. Perhaps one reason for this is that most of the companies manufacturing hospital beds in China are very small, smaller even than the many subsidiaries of the Hill-Rom, Stryker and other American brands. In fact, many of the Chinese companies are not pharmaceutical based but are instead steel companies who manufacture hospital beds for additional capital support. Currently one of the manufacturers of hospital beds in China is The Pharmaceutical and Medical Company of the Jianghan District located in Wuhan, China. The Pharmaceutical and Medical Company of the Jianghan District produces very few models of electronic hospital beds. In our research, we found only one motorized bed that was manufactured by this organization.

The hospital beds produced domestically in China tend to have very few frivolous functions. The most sophisticated bed produced in China is an ICU bed which features include polyethylene head and footboard, polyethylene side rails, stainless steel bed frame and patient support area. It also includes a central break wheel to keep the bed in place. This ICU bed can be seen in Figure 10 below.

Figure 10: Chinese Made ICU Bed

The less sophisticated beds manufactured by Chinese companies have many similar features to the more advanced ICU bed. These beds have polyethylene headboards and footboards, as well as polyethylene side rails. Often, their frames and patient surfaces are made of stainless steel and all have a centrally located break wheel. The major difference between the two beds is in the positioning of the bed surface. Where the ICU bed is adjusted through the use of an electric motor, the regular Med/Surg bed is adjusted by a nurse cranking the bed into position. The cranks are made from stainless steel. These hand cranks incorporate a German made damper to control the noise and speed of the crank, as well as allow for easy one handed cranking. A picture of this bed can be seen in Figure 11 below.

Figure 11: Chinese Made Med/Surg Bed

There are, however, several problems associated with hospital beds domestically produced in China. One of the major problems is the durability of the bed. The bed is not easily transported from one area to another due to the low quality castors attached to it. The bed will pull in unwanted directions resulting in the breakage of the castors and rendering the bed useless. The linkages between the crank and the lifts on the bed are also of very low quality. They often break resulting in a bed that can no longer be cranked into various positions resulting in an unusable bed. The cranks are also very heavy and require significant force to adjust the beds position even when there is no patient lying in the bed. For these various reasons many hospitals in China tend not to favor their domestically produced beds.

Instead of purchasing domestically produced hospital beds, many hospitals import beds from Japan because they are more durable and reliable than the Chinese beds but are far less expensive to purchase and ship than American-made beds. The Japanese beds have the same functions as the Chinese produced hospital beds, but last significantly longer. A bed imported from Japan may cost the hospital that is purchasing it up to 20,000 Yuan or about 2,500 US dollars. While these beds have costs comparable to those in the United States, their functions are far more limited than and only as equally reliable as American made beds. Hospitals in China are ultimately willing to pay that much for a bed they believe to be far superior to their own models, despite the fact their cost is extraordinary for the minimal functions provided.

2.3 National and International Governing Standards

Prior to any finalized design modifications significant research into regulations, including Chinese regulations and those determined by the International Standards Organization (ISO) were required. For additional safety and information, past research provided by the United States Food and Drug Administration was also considered. What follows is a summary of the standards found with regards to Hospital beds at both the Chinese national and the global levels.

2.3.1 Chinese National Standards

The Chinese government currently has in place a set of recommendations for the specifications of hospital beds. They are known as the Curatorial Industry Standards of China. These national standards cover almost every aspect of the bed and must be strongly considered before any design can begin to take shape. These standards will influence our designs to specific lengths, widths, and heights. These government recommendations also govern the degrees of patient movement within the bed including the backrest, and the knees. The Curatorial Industry Standards of China set a weight capacity that the bed can hold as well as the length of the safety guardrails. The specific Curatorial Industry Standards of China recommendations can be seen above in Table 1.

The parameters listed above in Table 1 will be the design specifications that we will work within. There are however some additional Curatorial Industry Standards of China parameters that we must consider in our design that are not listed above. If our bed is going to be powered manually, then the recommendations dictate that the handles must crank the bed into a sitting position rotating clockwise. We intend to design most of the features of our bed with the maximum values as our targets. However we will be designing to the minimum values for the bed height as well as the weight capacity for the bed. The Curatorial Industry Standards will greatly influence the final design of our hospital bed if we intend for its use within China.

Table 1: Curatorial Industry Standards of China for Hospital Beds

	Maximum Value	Minimum Value
Bed Length	200 cm	190cm
Bed Width	100cm	90cm
Bed Height	N/A	48cm
Backrest (Inclined)	90°	65°
Knee Gatch	180°	120°
Weight Capacity	N/A	240kg
Force Moment at Handle w/ no added weight	2 N×m	0 N×m
Guardrail Height	N/A	35cm
Guardrail Length	N/A	80cm

2.3.2 Food and Drug Administration Guidelines

The American Food and Drug Administration, or FDA, recently released a statement which discusses in extensive detail the many issues involving patient entrapment on Hospital Beds. In order to ensure the highest Safety Factor for patients in our bed design, we implemented the guidelines provided by the FDA to minimize the risk of patient entrapment while concurrently serving all Med/Surg functions.

The FDA performed extensive background research of their own and sought the information of such reputable organizations as the International Organization of Standards, Stryker International, Hill Rom, the American Red Cross and a number of top American hospitals to find out which areas of modern hospital beds are most dangerous for entrapment, ergonomic data, the number of entrapment occurrences over a number of years and the injuries that resulted.

The FDA concluded that there were seven zones which were most dangerous and made size recommendations for those zones to reduce the rate of patient entrapment. Combined knowledge of danger zones, as concluded from the hospitals and bed manufacturers, as well as the ergonomic data, the FDA made the following determined the seven danger zones as can be seen in the following Figure 12: Seven potential entrapment areas in hospital beds determined by the FDAFigure 12.

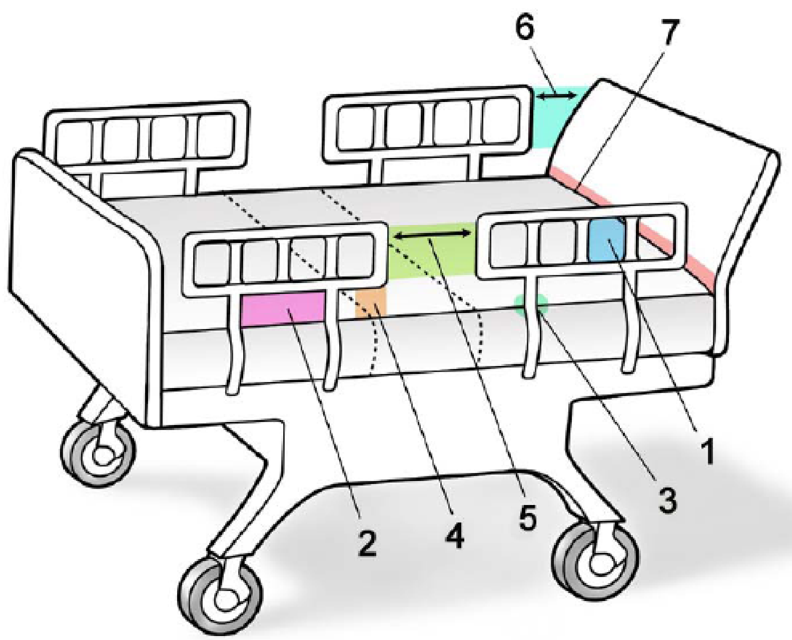


Figure 12: Seven potential entrapment areas in hospital beds determined by the FDA

The seven sections can be defined as follows:

- **Section 1** is the area of spacing within the rail
- **Section 2** is representative of the area under the rail, between the rail supports or next to a single rail support
- **Section 3** is the area between the rail and the mattress
- **Section 4** distinguishes the area under the rail, at the ends of the rail
- **Section 5** is defined as the area between split bed rails
- **Section 6** between the end of the rail and the side edge of the head or foot board
- **Section 7** clarifies the area between the head or footboard and the mattress end

Upon determining the seven zones where entrapment was most likely to occur, the FDA used ergonomic data from the National Center for Health Statistics to define the spatial limitations for four zones in bed design. Although the FDA recognizes seven potential sections of entrapment, only sections one through four have had dimensional limits recommended because they are the areas where entrapment is most likely to occur. A summary of the limitations imposed upon these zones is described in below.

Table 2: Summary of FDA Hospital Bed Dimensional Limit Recommendations

Zone	Dimensional Limit Recommendations
1 Within the rail	<120 mm (< 4 3/4 “)
2 Under the rail, between rail supports or next to a single rail support	< 120 mm (< 4 3/4 “)
3 Between rail and mattress	<120 mm (< 4 3/4 “)
4 Under the rail, at the ends of the rail	<60 mm (< 2 3/8 “) AND >60° angle

Although zones five through seven do not have dimensional limit recommendations, the FDA does recognize them as potential zones of entrapment and encourages facilities and manufacturers to report entrapment events in those zones. For Section 5, patients may suffer neck or chest entrapment from the space between the bedrails. Additionally, a V-shaped rail offers the potential for entrapment by wedging. Section 6 imposes the risk of entrapment for the face, neck or chest as a means of wedging in the corner. The FDA also realizes that different articulations for the bed may change the angle and/or spacing between those gaps and therefore encourages facilities and manufactures to report incidents of entrapment and to also research methods of minimizing the changing dimensional schemes at different bed articulations. Lastly, for Section 7 the FDA recognizes the area between the inside surface of the head board or foot board and the end of the mattress. In order to counter the risk of entrapment, the FDA recommends regular checkups on the bed to ensure that the head and foot boards are tightly in place, the mattress has not shifted drastically and that mattresses have not become overly compressible.

2.4 Tongji Hospital

Tongji Hospital is located in the city of Whuan, in the Hubai province of China. Tongji Hospital was opened to patients in 1991 and has been evaluated as a Class A general hospital by the National Health Ministry of China. This hospital currently has over 1000 patient beds, and employs a staff of over 1200, including doctors, nurses, medical technicians, and maintenance personnel. Tongji hospital currently operates fully functional cardiology, orthopedics, thoracic surgery, neurosurgery, endocrinology, pediatric hematology, psychiatry, obstetric and gynecology, dermatology, and imaging departments, as well as a clinical laboratory. Tongji Hospital is widely regarded as the best hospital in Wuhan.

2.4.1 Beds Used at Tongji Hospital

The hospital beds currently used at Tongji are not manufactured in China, but are imported from the Paramount Bed Company, located in Japan. Tongji Hospital will pay 20,000 R.M.B. or about $2,500 US for one of these Japanese beds. These beds are very basic and have limited patient functions. The bed's backrest, knee gatch, and height can all be adjusted to different positions. The bed is adjusted manually through cranks at the foot of each bed. This setup requires that the patients be completely dependent on the medical staff for bed adjustments. The bed also features a foot adjustment that can be manually changed by the nursing staff. The foot adjustment is not through a crank, but is however, changed by lifting that portion of the bed and supporting it with a metal bar inserted into various notches to achieve the desired angle. This bed also features a drop down side rail on the left and right side of the bed as well as locking castors. A picture of the Paramount bed used at Tongji Hospital can be seen in Figure 13 above right. The staff at Tongji Hospital is currently satisfied with the performance of the Paramount beds.

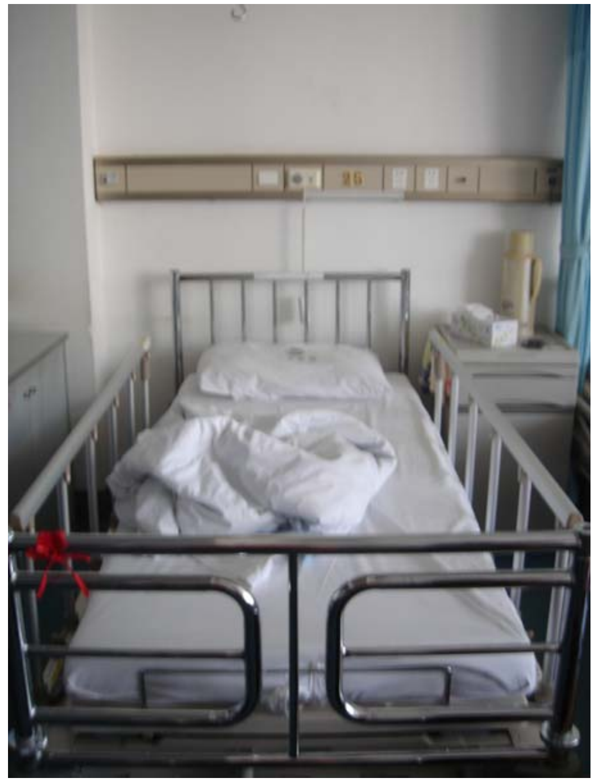


Figure 13: Paramount Bed from Tongji Hospital

2.5 Anthropometric Data

Anthropometric data is a collection of measurements to determine the length of a person's various appendages based on the height of that person. This data is determined by conducting numerous measurements on a random sample of people. Anthropometric data is crucial to the success of this project. Without the correct lengths of each section of our bed, in relation to the human body, this bed will be incredibly uncomfortable for the patient to use.

The specific anthropometric data that we will be concerning ourselves with for this project will directly relate to the parts of the body that we wish our bed to be adjustable at. Anthropometric data is available below in Figure 14. This data is all in relation to a person's overall height.

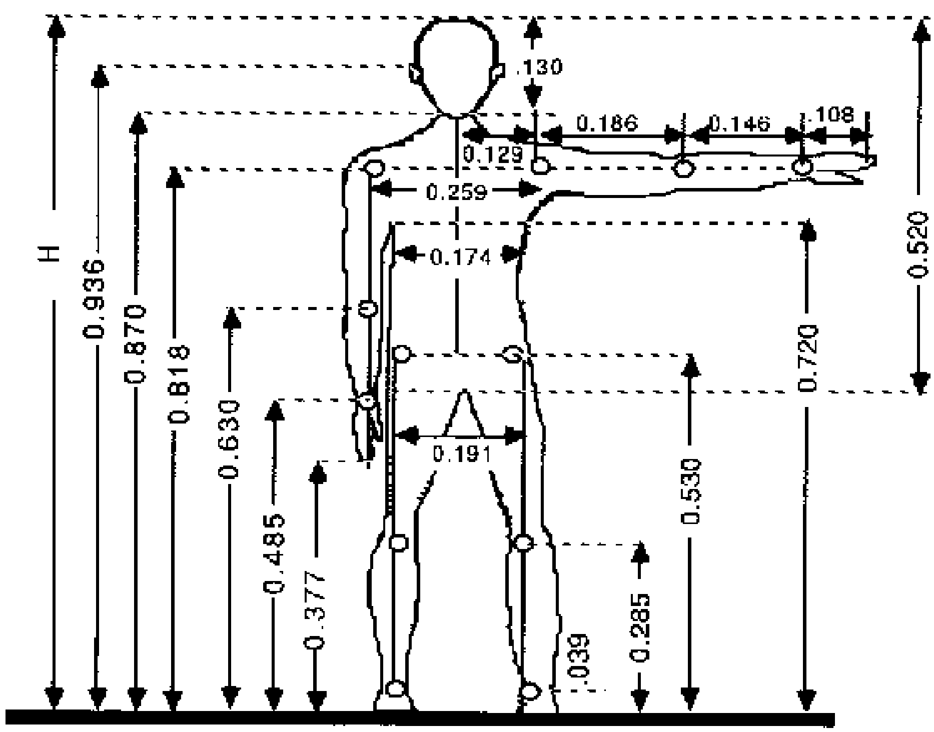


Figure 14: Anthropometric Data for a Person Standing

We used the data from the top of the head to the lower back to calculate the length of our backrest. To figure out that length we took the overall length of our bed as the person's height. Using the table we find that the length from the top of a persons head to the bottom of a person's lower back is 47% of their total height. We repeated this process using the anthropometric data for a person's Gluteus Maximus, their thigh length, and the length of a person's lower leg including the feet.

The second style of anthropometric data chart that we used is a person in a sitting position. In order to determine the characteristic lengths of each segment on our design for a hospital bed, we utilized the data of a person in the seated position since it most closely resembles the position one will be set in on a fully-inclined hospital bed. We used measurements 3.1, 3.9 and 3.6 on Error! Reference source not found.as seen below. Measurement 3.1 was used for the incline position of the back, 3.6 for the gluteus maximus slot and 3.9 was utilized for the upper-thigh length and positioning.

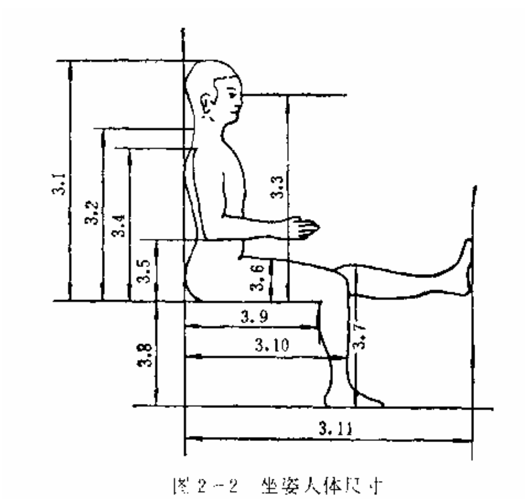


Figure 15: Anthropoemtric Data showing various human proportions

3 Methodology

The mission for this project was to design a reliable hospital bed for use in China that can be manufactured domestically. With the completion of this project we hoped that our bed design could be widely used throughout hospitals in China. We hope that by domestically manufacturing the bed, the price of the bed will be drastically reduced and allow for affordable modern health care to be provided to a significant portion of China's population.

Initially, we gathered literature from a number of resources regarding existing bed designs from nations with reputations for manufacturing reputable beds such as the United States and Japan and from a nation with a poor history of bed design, China. Upon collection of existing designs, we developed design matrices to determine what made a reliable hospital bed and which qualities the bed of our choice would employ and then developed CAD drawings using ProEngineer. Once successful completion of blueprints were developed, we manufactured a working prototype of our bed and then ran cross analyses for structural stability, stress resistance and other mechanical properties to ensure the bed's safety.

The team's ultimate goal of designing a reliable domestic hospital bed for China will be achieved through the subsequent completion of the following goals.

1.) To analyze all existing bed products and determine which are of the highest quality in relationship to price.

2.) To fabricate our own design for use in China based on the highest quality beds.

3.) To manufacture a prototype of our bed alterations.

4.) To determine and support the overall quality of the hospital bed.

3.1 Analyzing all Existing Hospital Bed Designs

Today's technology offers many different bed designs available for purchase by a medical care facility. These beds are produced by a wide range of companies in a wide range of countries. Each bed is designed for a specific use and the functions of that bed represent the situation that it will be used in. Our main focus was on the beds that are currently designed and manufactured in the United States and beds that are designed and manufactured in China. Initially, we performed extensive research into the beds that are on the market in each country as well as the brands and styles typically used by hospitals in the United States and China. Our secondary task was to decide on a bed design that most closely fit the needs of a Chinese hospital at a reasonable expenditure.

3.1.1 Evaluating Current Bed Designs

The first step to evaluating hospital bed designs was to find out what products were currently available. Our research started back in Worcester where we visited the University of Massachusetts Memorial Hospital to view beds currently being used in an American Hospital. We also reviewed existing hospital beds in books found at WPI's Gordon Library as well as Worcester Public Libraries. The library revealed minimal sources to us, but did lead to some information regarding FDA standards for hospital bed patient entrapment. The FDA recently released reports that new models of hospital beds used in the United States must have components which minimize the risk of patient entrapment including an emergency button for the patient to press and a warning signal in the event that an entrapment takes place. The chief engineer of the biomedical department at UMass Memorial met with us where he reported that the largest setback of existing hospital beds from an engineer's perspective is the location of the gearbox for repairs to electronic beds.

The engineer also gave us recommendations and standards regarding American hospital beds. He told us a number of functions regularly included with even the most inexpensive hospital beds including an elevating mechanism, an incline to 60º for the back, collapsible safety rails and a requirement that all electronic beds are grounded. Lastly, he recommended to us that we use larger casters than many beds currently employ which reduces the vibration to the patient when traveling over grooves and allows for easier traversing of spaces between the elevator and the floor.

The last steps in our literature review included a thorough examination of existing models from the two largest manufacturers in the United States: Hill-Rom and Stryker. We found that the beds they produce vary in regard to their accessories and ease of operation but that the performance of the mattresses and the degrees of freedom for the patient in each bed were similar. Standards for the Hill-Rom and Stryker beds can be seen in Appendix A: Existing American Bed Models.

We then made an effort to research hospital beds that are currently being produced in China. Our investigation led us to The Pharmaceutical and Medical Company of the Jianghan District, currently one of the few producers of hospital beds in China. We evaluated the pros and cons of their designs and compared them to the designs that are currently available in the United States. We found that many of the basic components and functions of the bed are similar, including the variable litter positioning as well as some basic safety functions including locking castors. However one main difference in the design is the opulence of the American made beds compared to the pure functionality of the Chinese beds. American beds use electric motors to adjust the litter position where the Chinese beds rely on manual power to do the same thing. American beds are also accompanied by many creature comforts including nightlights and built in televisions. These features all contribute to a higher price and increased bulk where Chinese beds are designed to be as small and economical as possible.

Our next step was to visit the Tongji Hospital in Wuhan, China and to see what type of medical beds they currently use in their orthopedic ward. We were allowed to examine a bed as well as interview the medical staff. We were able to draw many conclusions about the beds that are currently available at Tongji Hospital and are described in Section 2.4.1 Beds Used at Tongji Hospital. From talking with the medical staff we were also able to determine the current problems with the Chinese made hospital beds and why Chinese hospitals will not use them. The problems that we found with hospital beds designed in China are described at the bottom of Section 2.2 Chinese Hospital Beds. Our visit to Tongji Hospital provided us with very useful information about the functional needs of a bed for use in a Chinese hospital, as well as the problems associated with the commercially available beds currently produced in China.

3.1.2 Selecting the Best Bed Design

After we had completely reviewed all of the existing products available from companies in America, Japan and China, it was time to select a bed design. This bed design would be the one that most closely fit our ideal design for use in China. We went about deciding on the bed design by comparing the beds currently available and most widely used in both the United States and China, in a design matrix, which can be seen in Appendix A: Existing American Bed Models.

In order to properly assess a bed design for the demands of the Chinese hospital, we had to develop and appropriate matrix for evaluation. Each bed was ranked on a scale of 1-10 and each category had a certain percentage of importance for the overall function of the bed. The most important consideration was the satisfaction of the Curatorial Industry Standards to minimize ambiguities between what the hospitals used and the recommendations of the Chinese government. Durability and safety provided the second most important components for design intent because current beds produced in China are frowned upon for their proneness to failure while the safety of patients and staff is an obvious necessity. Poor durability of the beds increases their maintenance requirements thus contributing to additional costs, another important consideration in the bed design.

Manufacturability, cost and ease of operation provided the next largest sets of data for comparison. Manufacturability, or the opportunity to easily reproduce the bed within China, is an important component so that a high number of beds may be mass-produced to meet the demands of all hospitals and also to ensure the company who designs and sells such beds will not go belly-up in bankruptcy. The cost of the beds is extremely important so as to not only save hospitals money from bed purchases but also to satisfy the needs of the Chinese economy which is not nearly as prominent as the United States economy.

Rounding out the items for inclusion in the decision matrix were the ease of transportation, lower leg mobility, electrically powered functions and other additional features. Combined, these four components contribute to 16% of the bed design and were used for additional performance and marketability in our own design. A list and brief summary for each measure considered in the performance and determination of a good bed is as follows:

- **Curatorial Industry Standards (20%):** Includes recommendations for articulation angles, size of safety rails and end rails, height variances for bed, etc. This is the most important consideration because most beds in China follow these standards and they are a large component of hospitals' inclination to purchasing certain medical/surgical beds.
- **Durability (15%):** Durability includes the longevity and lifespan of the bed under normal working conditions, ranging anywhere from two years to twenty. Durability considers the material(s) the bed frame is designed from, the reliability of the type of motors used in electronic beds, and the ease and cost of reparability amongst other functions.
- **Safety (15%):** The safety of the hospital bed designs is a large consideration at 15% because if the beds provided by hospitals do not promote a healthy lifestyle for recovery the length of stay for the patients may be longer, injury may result to patient and/or staff and lawsuit liabilities are an option. The safety of each bed was determined by the material selections, compliance with CIS and FDA standards, stress analyses on the weakest sections of the beds and the functions provided in case of emergency, for instance the ability to achieve the Trendelenburg position.
- **Ease of Manufacturing (12%):** Ease of manufacturing is a significant consideration in bed design for a number of reasons, most notably the resultant

profit margin that would result from the production ratio, number of workers needed, development of unique parts, etc. Manufacturability was determined by the reproducible components on each bed, difficulty for assembly, estimated number of workers to complete each bed and approximation of time for completion of each bed.

- **Cost (12%):** Bed costs were considered in two dimensions. The first dimension considered was the actual cost of bed assembly and purchase whereas the second element was the cost of shipment to the hospital. Electronic beds manufactured in the United States, such as the Stryker and Hill-Rom brands, are substantially more expensive to manufacture than the Paramount hand-cranked beds however the cost of distribution for the American beds throughout the United States and the Paramount beds throughout China makes the cumulative cost of the two rather comparable.
- **Ease of Operation (10%):** Today's fast-paced world requires expediting processes as much as possible and in the hectic and crowded Chinese atmosphere, there is little time to waste while working in the hospital. One of the ways to reduce the nurse to patient time ratio is to make the beds easy to operate and easy to learn to operate. Although electronic beds have an advantage because the motors can move faster than any human, the hand cranked beds should be simple to use and as quick and efficient as possible.
- **Ease of Transportation (5%):** The ability to relocate a bed for surgeries, medical emergencies, room changes and other necessities is a concept very lowly regarded in American hospitals which have very limited spatial constraint

problems. Chinese hospitals however are filled to capacity and the navigability of the hospital beds is rather important to fit as many beds as possible into an area. Transportation therefore considered not only the ease to move a particular bed, but also the space required to move each bed.

- **Leg Mobility (5%):** Although the CIS have recommendations for the articulation of the upper leg, there is no consideration of the lower leg. Recent medical studies have revealed that the articulation of the lower leg along with the upper leg portion of the body can help a patient to regain full recovery in an expedited manner, will allow for patients to be far more comfortable and also reduces the number of pressure sores in long term patients. Therefore, a wide range of lower leg mobility as well as the ease to achieve such angles was a consideration for a good hospital bed design.
- **Electric Functions (4%):** Although all the American hospital beds we researched had electric functions to operate them, many Chinese hospitals use hand-cranked beds. The inclusion of electric functions in beds today makes it easier for patients to achieve more comfort as they themselves can often adjust their own beds to the patients' own comfort levels.
- **Additional Patient Functions (2%):** While features such as a night light, fifth wheel for added traction and extendable footboard are convenient they are not entirely necessary. However, in the determination of a good hospital bed, additional patient functions and aesthetics played a small role and resulted in the subtle differences giving certain beds the edge over a competitor.

Based upon the cumulative averages of the beds from the design matrix, you can see the Century+ and LTC Med/Surg beds manufactured respectfully by Hill-Rom and Strker, received the highest overall score based upon the criterion used for selection. Despite their many benefits, both ICU beds received rather low scores as result of their costliness, difficulty for manufacturability and the constant upkeep and funds that must be expended for their longevity. However, the lowest scoring beds overall were those currently produced in China, and for good reason. Current Chinese beds are widely unaccepted throughout China because they are so prone to failure, thus contributing to their low durability score. Quite frequently, the casters will crack, the articulating parts will fracture and the cranks will break off. Because the China-produced beds are so ineptly designed for durability, the safety of such beds suffers drastically. Contrary to the reliable Century+ and LTC beds, which meet not only most all Chinese Curatorial Industry standards but also satisfy the FDA safety rail recommendations, the Chinese-produced beds meet only the CIS standards and follow none of the FDA standards. The Wuhan-manufactured beds also do not provide any extra safety functions, for instance an automated CPR release mechanism.

Despite its relatively mediocre score, the Japanese-manufactured Paramount beds were determined to have ample opportunity for improvement with certain alterations. Most notably, if the exact same bed could be manufactured and delivered solely in China, the cost of the beds would decrease considerably. To further improve the beds, our group concluded that a strict following of both the CIS Table 1 and FDA Table 2 recommendations would provide more safety to the beds, increases their marketability and could be manufactured with no additional expenses accrued.

Thus, for final basis of our design selection we adopted features of the two highest scoring beds, the Hill-Rom Century+ and the Stryker LTC, and added those features to the potential of the Paramount beds. While we did not convert our own design into an electronically powered design, the opportunity does exist to change the bed from manually cranked to electrically driven and the power required for all articulating parts can be found in subsequent sections.

3.2 Fabrication of our own Bed Design

Although the primary focal point of our project was to design a bed that could be manufactured and distributed in China, we needed to make certain alterations to entice the Chinese hospitals into testing and purchasing our beds. The beds currently used in China, manufactured by Paramount, Ltd. provide only the basic entities of bed articulation and elevation changes. While our bed design focused primarily on these concepts, we found that it would be necessary to make a few changes so as to spark interest in our bed design.

3.2.1 Spatial and Angular Bed Dimensioning

Through the advanced notice of the Chief Engineer at the University of Massachusetts Medical Facilities along with the recommendations of the Chinese Curatorial Industry Standards, we selected the angular restraints of the bed. Most notably, every significant hospital bed has an upper body articulating mechanism and the CIS recommends it moves to a maximum angle of at least 60º. Based upon current beds along with regards to patient concerns, we felt that an angle of at least 75 º and as high as

80 º would be ideal. In order to establish a length for the entire hospital bed, we took into account both the anthropometric data that we had researched Figure 14 and the Curatorial Industry Standards. From both data sets, we established a nominal length of between 2000 and 2200mm for the length of the entire bed and also determined the length of the articulating back mechanism to be 90cm based upon the 95^{th}% of the anthropometric data researched.

The CIS recommendations also made notion of the fact for the minimum angle which may be accrued between the stationary buttocks and the upper-leg assembly. We found that angle, 60 º, to be more than satisfactory and thus adopted it for our own design and using the anthropometric data in the sitting position, which most closely relates to the position of an articulated hospital bed, found that the length of our upper leg segment should be roughly 35cm. Lastly, in order to ensure that the lower legs could articulate for a full range of motion, we sought to design a mechanism which could achieve an angle parallel to the ground for all ranges of motion in regards to the upper-leg assembly. Thus, at the most extreme angle in which the upper-leg assembly is inclined to its full 60º and a height of 30.3cm, the lower leg mechanism runs parallel to the ground also at a height of 30.3cm and at an angle of 150 º in regards to the upper-leg assembly. In a means as to satisfy the recommended overall length of the mechanism, as well as the recommendations from the anthropometric data that we researched, we selected a length of 50cm for the lower leg device which will satisfy the upper most percentage of adults in China.

3.2.2 Lower Leg Assembly Mechanism

The first consideration we wanted to deal with was the adjustment of the lower leg mechanism. This attribute is currently being addressed by most major hospital bed manufacturers but is still for the most part in its infant stages. Presently in the United States, beds that are electrically powered have been found to frequently short out at the lower leg assembly. The reason behind the power failure is that designers accounted only for the weight of the patient in the bed, neglecting to incorporate other factors such as the presence of visitors who often sit at the foot of the bed. Quite frequently, the motors try to exert too much power to compensate for visitors at the foot of the bed and the motors quickly burn out.

3.2.2.1 Currently Employed Lower Leg Lifting Mechanism

In beds like the Paramount model, which are manually cranked, the lower leg mechanism provides a different challenge. On these beds, the lower leg mechanism is adjusted after the upper leg assembly has been placed into its proper position. The lower leg mechanism is not adjusted manually by a crank, but by the nursing staff lifting the lower assembly and adjusting as can be seen in Figure 16.

Figure 16: Lower Leg Assembly mechanism of Paramount Bed

Often, this process requires two people to make the adjustment; one to hold up the patients' legs and the other to adjust the bed. If only one person is used to adjust the bed, much strength and effort must be exerted to make the adjustments.

As you can see from Figure 16, the current lower leg mechanism is supported initially by Part A which refers to the platform that the lower leg assembly rolls upon when the upper leg assembly is articulated. Part B reveals the mechanism which supports the lower leg assembly when it is lifted and articulated while Part C shows a reinforcement beam that runs the width of the bed to the other lower leg support mechanism. Lastly, Part D shows how the lower leg assembly is currently altered at certain degree increments up to the horizontal position.

3.2.2.2 The Parallelogram/Jack Lifting Iteration

Certain considerations were made before any attempts at designing a device. Initially, we convened to decide that the lower leg component of the bed would be able to articulate to a fully horizontal position in regards to the ground, a determination of the minimum weight which the mechanism must support as 40kg and to ensure that the designed mechanism would not interfere with the intent of other aspects of the bed. Other considerations provided were to minimize the size and cost of the mechanism, to minimize the vibration and shock experienced by the patient and to also make a device which could be manually adjusted or driven by a motorized crank.

We went through a number of iterations into selection of the lower leg lifting mechanism. Initially, we opted to design a device which would raise the lower leg system in a manner similar to how a carjack operates, as seen in Figure 17. The device would compress part D toward part B, thus pushing parts A and C out sideways, reducing the angle α when the bed was lowered. Conversely, the same angle α would increase and components A and C would narrow their displacement from each other as the bed would rise. Despite our best efforts, certain complications would arise when using this sort of device. The biggest concern was that a Static analysis of the device revealed that the force required to raise

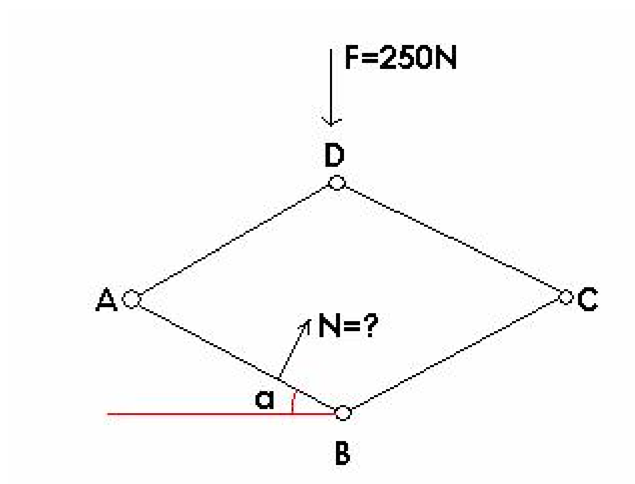


Figure 17: Lower Leg Parallelogram Lifting Mechanism

and lower the bed would range from 126.22N to 176.78N for the extreme bed elevations, numbers that far exceed the 2N*m as recommended by the CIS.

Because the moment of the handle required was far exceeded by the initial concept, we modified the device to be the same mechanism but placed on sliders as seen in Figure 18. From there, we were able to determine that a force of 125N in the y-direction was required on each slider to keep stable and prevent from collapsing. Also, a force of approximately 900N was required in the x-direction to keep the device from sliding out and consequently collapsing. From the 900N force that was required to keep the bed from moving in the x-direction, we were able to discover the torque necessary to rotate the worm gear, which proved to be 1.696N*m. Although that number is below the 2N*m recommended by the Chinese Curatorial Industry Standards, we felt a lower moment of the handle could be achieved.

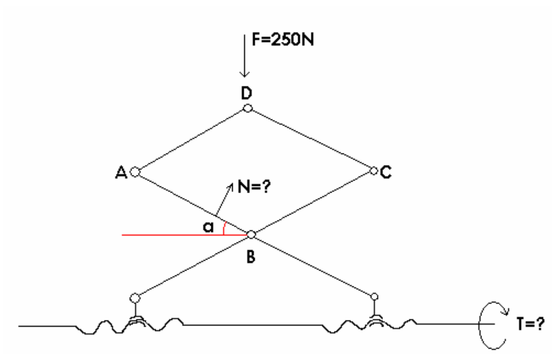


Figure 18: Jack mechanism utilizing a worm gear for movement

Another complexity with the sliding parallelogram device arose in that it could not translate to accompany for the motion of the lower leg mechanism as the upper leg mechanism was inclined completely to an angle of 60 degrees. The lower leg board translates along the surface in excess of 25cm and thus the sliding jack would have to have been placed back at least 25cm and would therefore consume a great deal of space in an already-crowded area of the bed.

3.2.2.3 The Slider-Crank Lifting Device

One of our many considered iterations was a slider-crank mechanism which would lift the lower leg independently of the upper leg movement. The mechanism would have been designed such that as the upper leg was cranked upward, the lower leg mechanism would move along as a slider so that it remained grounded and could be independently changed. Upon the completion of the articulation of the upper leg mechanism, the lower leg could then be cranked too. Prior to any mathematical analyses, we realized that this concept was good in theory but difficult in reality because in order for the slider to be raised, it would have required a great deal of force in the x-direction to initiate articulation.

3.2.2.4 Final Selection: Worm Gear Acting as a Slider-Crank

What then does our design offer? Our final design combines the mechanics of the slider-crank mechanism with the rolling device at the end of the lower leg portion already in place for existing beds. In order to keep the manufacturing cost down, the lower leg mechanism of our bed is manually cranked to adjust the bed, same as the slider-crank lifting device. The crank attaches to the platform that the

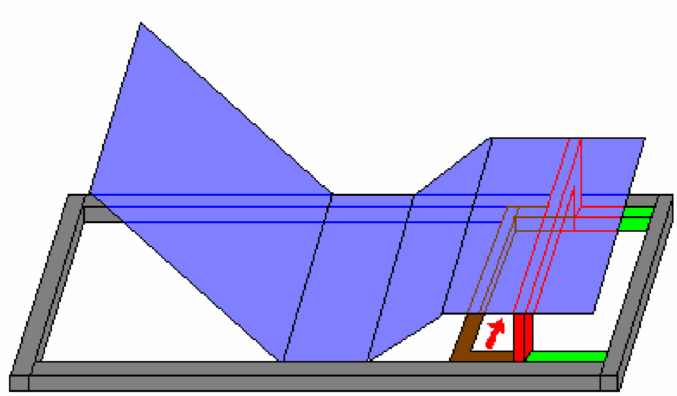


Figure 19: Final Design, crank-driven worm gear to lift the lower legs

lower leg of the Paramount currently rolls along. A support beam cuts across the bed to which the worm gear is attached. The crank rotates the worm gear, consequently allowing for a slider to move along the gear. As the slider traverses, the link it is attached to will rotate freely, thus lifting the lower leg section of the bed. Our preliminary sketch, Figure 19, shows in a simple manner how the bed will articulate. The only portion of the platform that rises is the two links where the wheels for the lower leg assembly are supported. The other portions of the platform provide a dust cover over the crank mechanisms and will therefore remain fixed. The final lower leg lifting design can be seen in Figure 20 below.

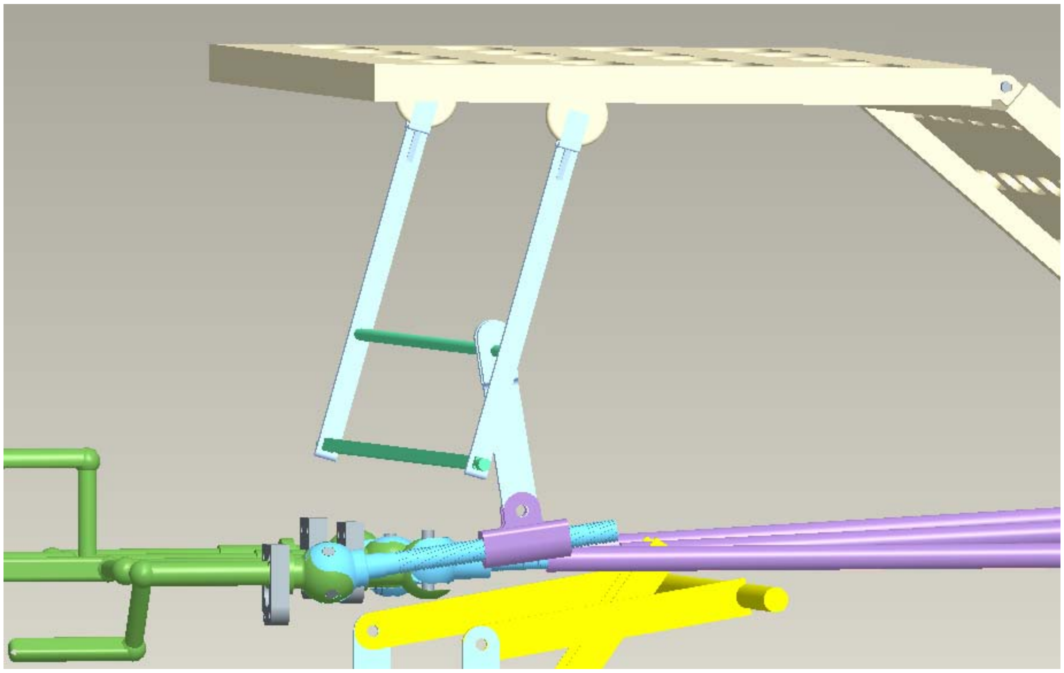


Figure 20: Complete Lower Leg Lifting Mechanism

Mathematical analyses for the final worm gear lifting device can be found in the subsequent results section.

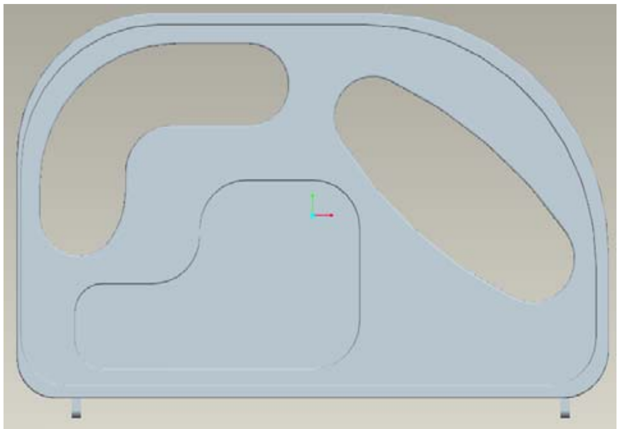
The sizing determination of the set was based upon simple trigonometry. We first calculated the height that the upper leg device would achieve when in full articulation at 60degrees. Based upon that information, we found that the maximum vertical height of the upper leg mechanism would be a distance of 30cm from the platform that the litter assembly rests upon. Therefore, the roller bar had to achieve that same vertical height, but to minimize the risk of breaking we determined the piece should maintain a slight angle of 20 degrees when it was in maximum position. Again, using simple trigonometry, we determined that the length of the roller bar to be 32.2cm.

Once we had the sizing calculations determined, the design of the screw and nut pair and the support beams we had to determine if the assembly could be packaged and fit accordingly into our bed design. While it was feasible to perform mathematical determination of this packaging, we found a visual to be more appropriate and from the preceding Figure 20 it is apparent that there will be no interference between the upper leg litter and the lower leg lifting mechanism's roller bar.

3.2.3 Headboard, Footboard and Guardrail Design

Certain compliances exist between the designs of the safety rails of hospital beds and the Chinese Curatorial Industry Standards. In addition to the recommendations of the CIS, the American Food and Drug Administration also mandates many performance features of their own for hospital beds operated within the United States. In order to improve safety features and increase the marketability of our own bed, we developed our own headboard, footboard and guardrail design respectfully.

Our most important alteration to the beds currently employed by Chinese hospitals such as Tongji was to improve the function of the safety rails. First, we recognized that the use of two safety rails on each side as opposed to one provided multiple functions. Two safety rails allows for spacing between the two rails which gives the patient a means of exiting the bed while doubly featuring as a support device to assist in departure from the bed. The addition of a second safety rail on each side also gives the patient the opportunity to raise and lower one or both rails on each side at a time, minimizing the claustrophobic sensation that may arise when only one rail is available on each side. The addition of a second safety rail on each side provides each patient the opportunity to have more mobility and degrees of freedom with certain parts of their body and allows the patient to protect other parts of the body based upon the extent of their injury. For instance, if the left leg were broke, the patient may need only the lower left safety rail up and could have movement for both arms and the right leg as desired while securing in place the injured left leg. Additionally, each guard rail satisfied both the Curatorial Industry Standards and FDA Standards by meeting cumulative length, minimal radii and minimal gaps as defined in previous sections. Lastly, the designs of the guard rails have more complex patterns, thus improving the aesthetics of the bed while maintaining no additional cost components, as compared to the Paramount models. Refer to Figure 21and Figure 22 for a visual of how the guardrail mechanisms have been designed.



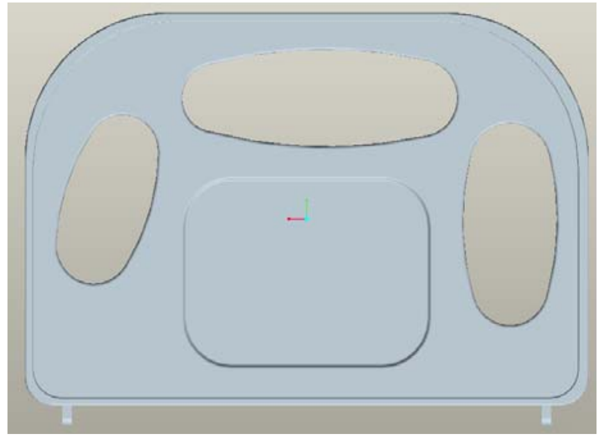


Figure 21: Guardrail at Foot of Bed **Figure 22: Guardrail at Head of Bed**

The headboard and footboard likewise meet both the CIS and FDA recommendations by amply satisfying the spatial restraints set. The headboard and footboard, like the guardrails, are also provided with unique patterns to improve upon the aesthetics of the Paramount designs. Despite these considerations, the two most notable satisfactory components of the headboard and footboard is the ease of use for them. A subsequent visit to Union Hospital in Wuhan revealed that, unlike the boards which used hinges in the Tongji hospital as seen below in Figure 23, an end board placed on a simple cylinder and removed by lifting was much simpler to operate.

Figure 23: Headboard and Footboard Hinge Mechanism on Paramount Beds

We decided that it would be this style of head and footboard that we would use as the basis for our own design.

We felt that there were certain medical advantages to a head and footboard that could be removed with such ease. Most significantly if a patient were to “crash” it would be extremely advantageous to be able to remove the headboard quickly so the medical staff would be able to stand behind the patients head. This would ensure that the doctors and the nurses would have plenty of effective working room around the patient. Another design consideration that we focused on was to attach the headboard directly to the frame instead of to the backboard. This is the method of attachment for many of the beds that we have seen. This design allows for the headboard to remain in the correct position while the backboard is articulated in various positions. This will allow the medical staff to be able to transport the bed by pushing with correct posture, making it much easier to move and reducing the strain on the nurses back. The advantage of this feature that is offered to the patient is that they can be transported with the backboard in any articulated position, increasing comfort. The headboard can be seen below in Figure 24, and the frame where the headboard is attached can be seen below in Figure 25.

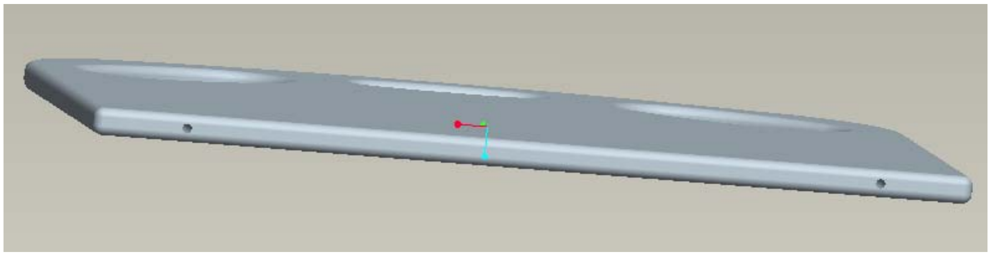


Figure 24: Headboard with holes for attachment

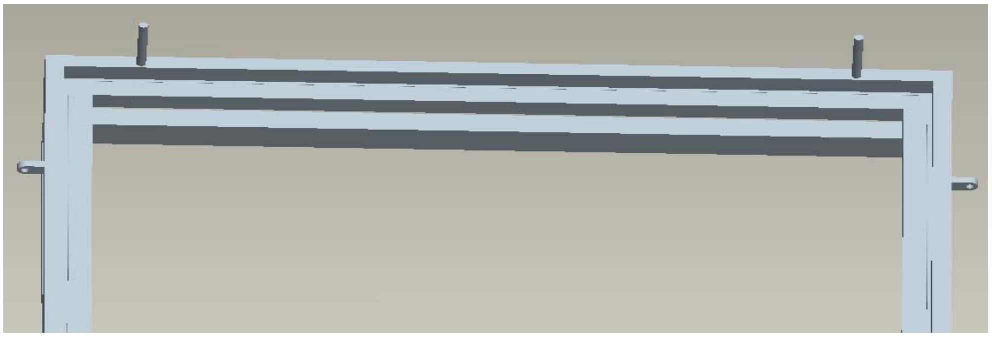


Figure 25: Frame with pins for headboard attachment

3.2.4 Articulation of Back and Upper Leg Board

Further design consideration must be given to both the backboard adjustment as well as the upper leg board. We felt that the current system in place on the Paramount bed currently used at Tongji Hospital was satisfactory to our needs, so we based our design off of the Paramount bed. With that being said, however, there were certain external factors that we had to consider that would affect the final design.

The linkages for the articulation of the backboard and the upper leg board use an identical design. The major consideration for this design was the amount of space that is available underneath the bed. There was a limited amount of space due to the mechanisms that raise and lower the upper bed frame, and the linkages that articulate the lower leg board. In the interest of saving space our design employs a universal joint as well as a screw and worm gear. This system will allow for an almost straight connection between the crank handle and the back and upper leg boards. The parts are articulated by manually cranking a handle at the foot of the bed. Both the backboard and the upper leg board are manipulated by separate cranks and will not move at the same time unless both handles are turned together. These handles then transfer motion to a universal joint. The joint rotates and turns the screw that is attached to it. The screw then turns inside the worm gear. The worm gear is then attached to a shaft which is connected to the backboard or the upper leg board. This system can be seen to the right in Figure 26. Depending on the direction that the handle is cranked in, the screw will wither elongate or retract within the worm gear shaft. This will produce a motion that either pushes the back or upper leg board up,

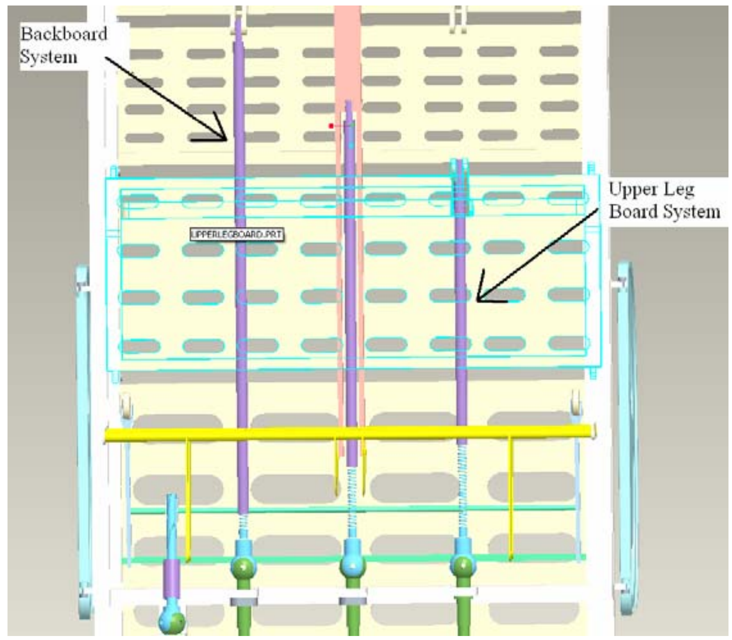


Figure 26: Backboard and Upper Leg Board Articulation Systems

or pulls them down. It is this system that allows for the adjustment of both the back and the upper leg board.

The biggest design obstacle for this system was dealing with the movement of the screw and worm gear when the back and upper leg boards are moved. As the parts are cranked into place, the position of the attachment of the worm gear shaft on the part will also change its location. The implementation of a universal joint solved that problem extremely well. The advantage of the universal joint is that it has two degrees of freedom. It can not only rotate, but can also move in the y-direction. The y-motion of the joint is crucial to the success of our design. This way we would be able to transfer the motion of the crank to the screw no matter what position the upper leg board or the backboard is in.

3.2.5 Bed Raising and Lowering Mechanism

An additional feature of the bed that needed to be designed was the linkage system that would raise and lower the entire top portion of the bed. We once again turned to the beds that are currently on the market. After a thorough review of the products we found a linkage system that, after a few modifications, would work well on our bed.

Our bed employs a parallelogram linkage system at both the head and the foot of the bed. The links are divided into two separate pieces which are then connected to the lower bed and upper bed frames. The parallelogram linkages are connected together by a rod across the top of the links. This rod ensures that the two ends of the bed will rise at the same time and in turn evenly raise the bed. The upper bed frame is raised and lowered using the same screw and worm gear method as is used for the back and upper leg. A handle is cranked manually, the motion is transferred to the U-joint, which turns a screw which lengthens or contracts the worm gear shaft. The worm gear shaft is attached to the rod that connects the front and back linkage systems and either pulls the rod raising the top frame of the bed up or pushes the rod down lowering the top part of the bed. The parallelogram linkage can be seen below in Figure 27.

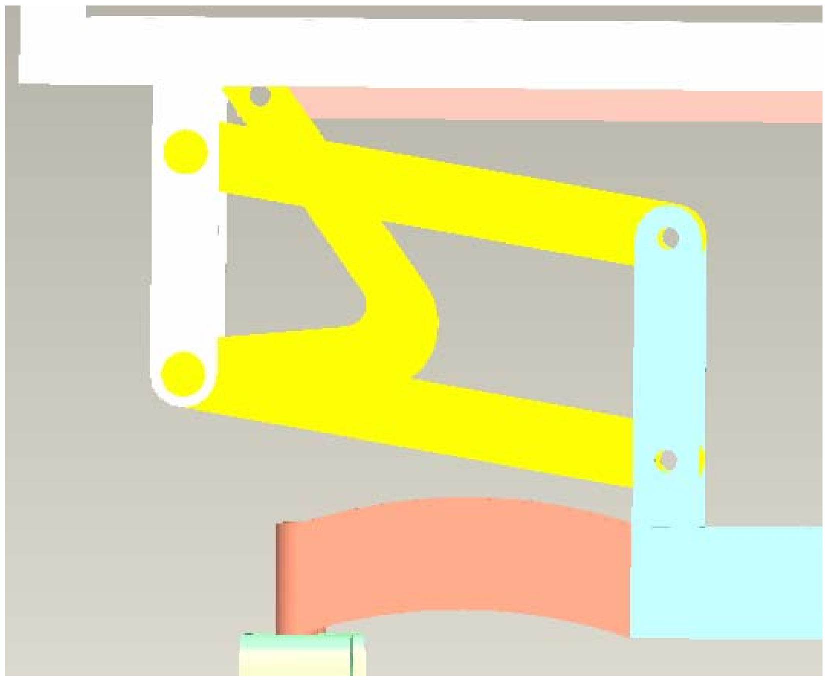


Figure 27: Parallelogram Linkage to Raise and Lower the Bed

There were two major design considerations for this specific linkage. There is limited space in the hospital wards so we could not have the bed traversing large distances in the X-direction as it moves in the Y-direction. Our design does move in the X-direction but it is minimal. There is a total of three centimeters difference in the horizontal position of the top portion of the bed at its highest and its lowest points. We feel that this is an acceptable distance and will not cause any inconveniences in the hospital ward where the bed is used. Another consideration was the Chinese Curatorial Industry Standards for the maximum height of the bed. These standards dictate that the bed must be no higher the forty eight centimeters from the floor to the top of the litter. To comply with these standards it required us to regulate the length of our linkage bars to no more then nineteen centimeters. We decided to use the full allowable length for our design so that we would get the maximum range of vertical motion out of our bed. Our mechanism for raising and lowering the bed was designed to minimize the space required in the hospital ward and to comply with the Chinese standards.

3.2.6 Complete Bed Design

Following the completion of the prior designs, the entire bed would have to be constructed. In the previous sections we have given detailed descriptions of how and why we designed specific parts of the bed the way that we did. We had modeled all the parts of the bed in Pro Engineer as we designed them therefore completion of the bed design required only assembly of the various parts together in ProE.

We started by setting the bottom frame of the bed as the fixed point that all the other parts would move around. Next the bed raising mechanism described in Section 3.2.5 Bed Raising and Lowering Mechanism was attached to the lower frame. The upper bed frame, including the litter, guard rails, and head and footboard, were attached to the lifting mechanism. The lower leg lifting assembly was then pinned in place on the bed frame. Lastly all the cranks, universal joints, screws, and worm gears were installed and attached to their corresponding parts. A completed design of our hospital bed can be seen below in Figure 28.

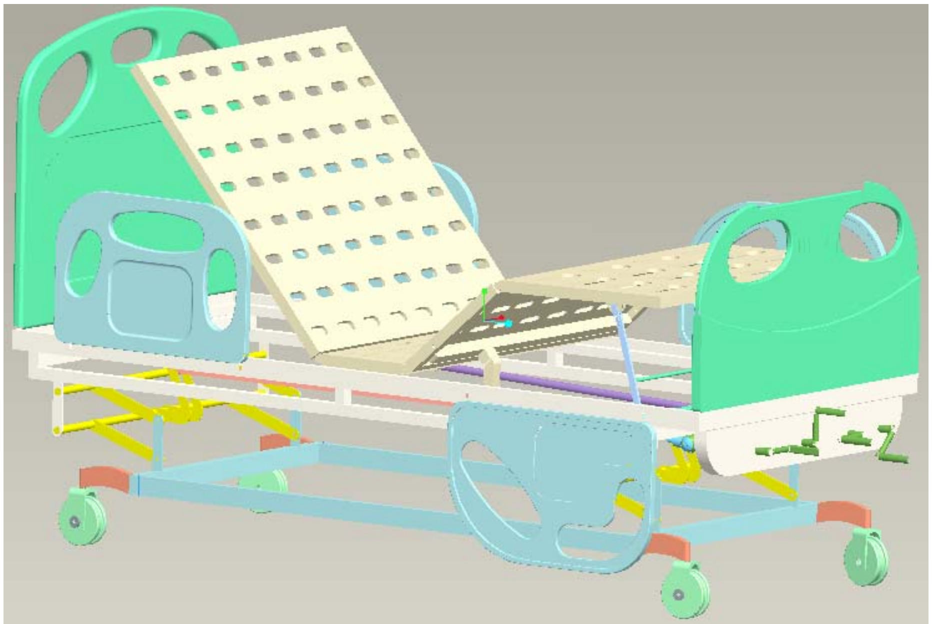


Figure 28: Complete Bed

3.3 Preparation for Prototyping

After the successful completion of the entire bed design we needed to determine if the bed would work. We ran considerable analysis in ProE and all indications pointed to a successful bed design. However the only way that we would find out if the design would work in a realistic manner was to machine the parts of our bed and create a prototype. Much of our complete bed model had been adapted from current designs so we were confident that they would work. The lower leg lifting mechanism, however, is an entirely new design, and thus far unproven. It was for this reason that we felt it was necessary to prepare our design for prototyping.

3.3.1 Orthographic Drawings

Before any parts could be machined, we had to develop a complete set of orthographic drawings for each part we wished to have machined. We, however, had to decide on what parts would be machined for us, and what parts were commercially available. Another consideration that weighed heavily into whether we would machine the parts or if we would purchase them was the price. If it was more expensive to buy a part then to have it machined it obviously it would be more advantageous to have it machined. Further consideration, however, revealed our limited amount of time to have our parts machined. It became more advantageous for us to buy as many commercially available parts as possible, providing the price was not that significantly higher than machining them ourselves.

The lower leg lifting mechanism has a total of 13 different parts. We discovered that there were seven existing parts that we could purchase. This left us with a total of six parts that we were required to machine. The parts that we purchased included the lower leg lift wheels, the U-joint, the lower leg board wheels, the wheel attachments, the worm gear/screw and the bed frame. The bed frame was recycled from a previous project, and through some modifications we were able to obtain the cut out of the lower and upper leg boards from the frame. Our group then needed to machine the lower leg lift bar, the lower leg link bar, the lower leg link brace, the lower leg link slider and the lower leg support bar for the lower leg link. These were all parts that we could either not find commercially or felt were too exact to try and modify from an existing product.

With a list of parts that were required for machining it was necessary to create engineering drawings of the parts. Our group members did not machine the parts. Instead the orthographic drawings were taken to the factory on the HUST campus and produced there. The drawings for the required parts were made using ProE, and delivered to the factory for fabrication. The complete set of 2-D orthographic drawings of the machined parts of the lower leg can be seen in

Appendix C: Orthographic Drawings for the Lower Leg Lifting Mechanism. The remainder of the orthographic drawings for our unique overall bed design can be found in Appendix D: Other Orthographic Drawings.

3.4 Supporting the Overall Quality of Our Bed Design

The completion of the design of the bed left our team with only one remaining goal. We needed to prove why our bed is better then the rest of the beds that are currently being used within Chinese hospitals. If we could not produce a satisfactory bed then there would be no reason for the hospitals to change from their current beds to ours, which was the ultimate goal of this project. Our team had to prove beyond a reasonable doubt that our bed was indeed better then the Paramount design currently in use.

3.4.1 Adherence to the Curatorial Industry Standards of China

To validate our bed design we turned to the design matrix that we created as part of Section 3.1.2 Selecting the Best Bed Design. We ranked our bed along side the other ten beds in the matrix, and determined the best overall bed using the ten categories that were previously described in Section 3.1.2 Selecting the Best Bed Design. The first and most important feature of our bed design is its compliance with the Curatorial Industry Standards of China. We followed the regulations and suggestions set forward by the CIS very closely. Our design meets all of the length, width, and height requirements that can be found from Table 1: Curatorial Industry Standards of China for Hospital Beds. Our design also features a dual guardrail design whereby there is one guardrail for the upper body and one guardrail for the lower body on each side, but the guardrails still maintain the correct length and correct height as suggested by the CIS. The backrest has incline capabilities up to 75° and the upper leg board inclines no more then 120° from the gluteus board as recommended by the CIS.   Additionally, our bed supports greater than a 240 kg load as mandated by the CIS. Our articulation systems also requires a force no greater then 2N×m to operate and our bed requires a maximum torque of only .69N*m.. Our bed was created with the Curatorial Industry Standards as a primary concern and the design satisfies them completely.

3.4.2 Bed Safety

The safety provided by the bed to hospital staff and patients alike was a major consideration in the development of our bed. Our bed not only took into account the Curatorial Industry Standards described above, but it also utilizes information published by the FDA on patient entrapment within the bed. Our guard rails were designed so that there is no space within the rail that has a distance greater than 120 mm. The guard rails developed are designed with minimal gaps and unlike the paramount beds, there are no slots which would more easily get the patient entrapped. The rails are attached to the bed frame in a way that ensures that there is gap no larger then 120 mm between the mattress and the rail and designed such that no gap is greater than 60 mm between the rails and the headboard and footboard. Our bed design also features a headboard and a footboard that can be removed quickly should a medical emergency with the patient arise. Our design maximizes patient safety by ensuring that patient entrapment will be kept to a minimum. Lastly, with safety as a large component of interest, we performed stress analyses on the parts of the bed which would be under the most pressure to ensure that the bed would not bend or break. The bed proved very strong and resilient with support of our claims in the section 4 Results & Analysis.

The manufacturability of our bed was of significant interest to the group. We wanted our design to be able to be manufactured quickly and precisely to keep the cost down while maintaining a high quality of the individual parts and overall assembly of the bed. We tried to incorporate as many prefabricated parts into our bed as possible. Our U-joints, screws, worm gears, wheels, and pins are all commercially available cutting the machining time for each bed. Our design further simplifies the manufacturing process by employing a lot of straight bars and rods with little adaptation needed. There are, however, complicated parts in our design. It is these parts that will increase the manufacturing time, increase the material wasted, and ultimately drive up the price. Unfortunately, there is no way to circumvent the use of the negative elements of our bed design.

The cost per bed is one of the most critical factors a hospital will look at before deciding on a bed design. If the cost of the bed is too high the consumer will choose to look towards another model. However to keep the price low, the design must sacrifice reliability, quality of materials and ultimately functionality. Our bed design tried to blend a bed design with increased functions, while maintaining a moderate price. The major advantage our bed has over the other beds currently available is that it will be produced in China. The domestic production of the bed will allow for a considerable decrease in price because the shipping and import fees will be eliminated. However there is an increase in the price of the bed due to the complex design of some of our parts. There is also an increase in the price of our bed because of the additional functions that our design will offer. The advantages offered by the articulation of the lower leg will far out way any increase in cost. Our overall estimate of the price of the manually operated bed will be approximately $875 American or 7000RMB in the Chinese currency while the electric bed would be slightly more expensive at around $1200US or 9600RMB.

The ease of the beds operation was another concern that was addressed with our design. If the bed is to difficult for the nursing staff to use then the design will not court favor in the medical community. Our bed design follows the Curatorial Industry Standards for force required to operate the crank handles as described above. Our bed also features the lower leg lifting mechanism which makes adjusting patient positions easy. Instead of one nurse struggling to lift a patient's legs or occupying the time of two nurses, our design allows for a patients lower legs to be adjusted easily by one nurse. Another advantage of our design is the backboard is attached directly to the upper frame. This feature allows the nurses to push or pull the bed with limited strain on their backs. This will help prevent nurses from incurring repetitive stress injuries and in turn, save the hospital significant amounts of money for days of missed work. Our bed design allows one nurse to do tasks that would normally take two or sometimes three nurses.

A feature similar to the ease of our beds operation is the transportability of the bed. Our bed is designed to be extremely maneuverable. There are many advantages our bed has because it is very maneuverable. Our bed features four independently rotating twelve centimeter castors. These large castors allow the bed to traverse large gaps between the floor and the elevator with ease. The large castors also allow the bed to ride smoothly decreasing patient discomfort in travel. The fact that the castors swivel independently of each other allows the bed to be maneuvered into extremely tight quarters. This makes placing many beds in a single room much easier as well as allowing beds to be transported out of the tight space while a patient is in the bed. High bed maneuverability will allows a busy Chinese hospital like Tongji to house many beds, and run exceptionally smooth.

The articulation of the lower leg is the key additional feature of our bed. The independently cranked articulation of a patient's lower leg is currently offered on a very limited number of bed designs including ours. This was the major design focus of our project. As stated before this feature allows a patient to rest and recuperate faster, and more comfortably while minimizing the time it takes a nurse to adjust the lower legs. Our design requires only one nurse for this job so more nurses are free to attend to the other patients in the ward. This design feature offers many advantages and little or no disadvantages. A bed designed with a system for the easy articulation of the lower leg region, is ultimately, a better bed. While the bed reduces the number of nurses needed for adjustment to only one, it also allows the patient to remain seated in the bed. Additionally, there is a full range of motion for any angle desired by the patient, a feature which is revolutionary for all hospital beds currently on the market. This feature alone will make our bed more marketable. The lower leg device should be desirable for beds not only in China but throughout the civilized world.

The final features on which our design was judged are electrically powered litter adjustments, and additional patient features. A bed that is electrically powered and controlled is much easier to use but there is a decrease in the durability and overall safety of that bed design, as well as a significant spike in cost. Another of our considerations was into additional patient features. Such features would include a nightlight, a telephone, or a television. It was our opinion, as a group, that our design would be focused more on functionally and less of frivolous features. It was for this reason that we decided to design our bed to be manually powered. However, we also realized the need for electric beds in the world so the following section on Results and Analyses will have details of the power required and a motor selection should we convert our bed to have electric capabilities. We designed a bed that would last a long time, be easy to maintain, and cost as little as possible. An updated design matrix including our original bed design can be seen in Appendix B: Hospital Bed Design Matrices.

4 Results & Analysis

After completion of our objectives, including the fabrication, manufacturing and support of our bed design, we ran a number of tests to ensure that our bed was indeed manufactured in a manner which could meet production guidelines. Most importantly, we ran a number of select mathematical operations to calculate the stresses on beams supporting the highest loads, pins with the highest loads, moment and power required to articulate parts of the bed for manual and electric beds respectively.

4.1 Mechanics Calculations of the Lower Leg Lifting Mechanism

The first check performed was a simple calculation of the degrees of freedom of the entire lower leg lifting assembly. We wanted to make sure that the screw pair would in fact rotate and allow the raising and lowering of the roller bar. We found that there was in fact only one degree of freedom in the lower leg assembly device, revealing that our projected movements were satisfied and that the roller bar's only movement would be in a radial direction therefore articulating the lower leg litter as desired.

Our second check which then had to be performed to ensure the safety of our device was a mechanics determination of the lower leg lifting device itself, including a Statics analysis to determine the maximum forces felt by the device and the moment imposed at the pin of the link. As was previously described in our selection process, our rejected iterations failed as a result of the requirement of too high a moment or for the inability to account for the translation of the lower leg board movement. We found that the highest force which would be imposed upon the slider portion, Fs in Appendix E: Lower Leg Lifting Device Mechanics Analyses, was about 578N. From that determination, we were able to calculate the torque necessary to rotate the crank as only .69N*m at the maximum, far less than the 2.0N*m maximum that is allowable as governed by the CIS. The lower leg mechanism analyses, including the degrees of freedom, forces and the torque requirements all have completed equations performed using MathCAD software and are viewable in Appendix E: Lower Leg Lifting Device Mechanics Analyses.

4.2 Determination of the Screw

After reassurance of the single-DOF for the lower leg lifting assembly and a calculation of the maximum torque requirement, we found it necessary to calculate the forces on the screw component of the lifting device since it would be under the highest stress and be most prone to bending and deflection. The preliminary task to determining the security of the worm gear pair was to make sure that screw pair could in fact lock itself when not being supported by the person or motor cranking. Utilizing standard equations for screws, we found that psi (Ψ) was significantly smaller than rho(ρ) and therefore, the screw pair is in fact able to lock itself when no external forces are placed upon the crank. For complete calculation details, please refer to Appendix F: Security of the Screw and Nut, Equation 4.

The second aspect of the worm gear that was necessary to determine came from Equation 5 in the text. The dual equations shown reveal first that the friction factor ps is .176MPA while [p] is somewhere between 18 and 25MPa. Since the determined constant is less than 1/100 of [p], it is determined that the friction factor may be ignored since it will have only minimal effect on the overall moment required to turn the handle.

Similarly, the shear stress found was a mere 2.217MPa compared to the 30-40MPA maximums which were determined by Weiguo Zhang's book.

5 Summary

Through the completion of this project we were made aware of the medical situation in an industrializing nation. Our project team was able to gain valuable first hand experiences of the current status of Chinese metropolitan hospitals through various interviews and hospital visits. We were able to take the information that was obtained through these visits and apply it to our project design. Our bed design synthesis consisted of modifications to a previously determined bed design as well as an original design for the lower leg lifting mechanism. The completion of our bed design then led to an evaluation of our bed design in comparison to beds that are currently available to the medical community. Our project was designed to allow the Chinese to domestically produce functional and reliable beds for their countries hospitals.

Upon our arrival in China, our first task was to determine the bed design that Chinese hospitals are currently using. Our project team visited two hospitals in Wuhan to get an idea what beds they were currently using. We were allowed to visit the orthopedic ward at Tongji Hospital as well as the ICU at Union Hospital. From these visits we determined that Tongji Hospital uses a bed that produced by the Paramount company in Japan. This bed articulates at the back as well as the upper legs, and has an adjustable bed height. The bed in use at the ICU ward at Union Hospital had an articulating back section and a pinned, dependent articulation between the upper and lower legs. These hospital visits allowed us to gain valuable information about the beds currently in use in Chinese hospitals.

Our bed design is based of the best features of a few bed designs and includes our modifications and additional design features. Our project team did a full evaluation of many products that are currently on the market in both the United States and China. Our bed design was based off of the Paramount bed found at Tongji Hospital as well as Med/Surg beds from the Hill-Rom and Stryker companies in the United States. Our team decided upon these designs by utilizing a weighted design matrix that compared the desired features of a variety of bed designs. This would allow our team to get a base idea of our bed design. Our team then decided upon the modifications that we would make to the current designs to make them better. We decided that we would improve upon the guardrails so that a zero transfer gap between beds could be achieved. We also decided that quick release head and foot boards would be advantageous. The main alteration of our bed design however was the articulation of a patient's lower legs independent of the articulation of the patient's upper legs. To articulate the lower legs we used a crank driven worm gear that would be attached to slider type linkage. Our design ultimately has an adjustable bed height as well as an articulating back rest, upper leg board, and lower leg board. Our design is capable of much more then the manually operated hospital bed currently in use in China.

The last part of our project was the validation of the reliability of our own design. This took us back to the design matrix that was used to evaluate the original designs. We compared our design with the others and found it to be superior to the beds that Chinese hospitals currently employ. Our design did however fall short of some of the beds that are produced in the United States. This is due to the motor driven capabilities of these beds. If however a motor was to be added to our design it would rank as high as these designs as well. We then analyzed all the major linkages within our bed to determine their reliability. Our bed design is a viable option for use in Chinese hospitals as a replacement to their current beds. Our task was to design a reliable hospital bed that could be domestically produced for use in China, and that is what we have done.

6 Conclusion

Through the completion of this design project our group has concluded that there is still much the Chinese can do to advance their health care system. Chinese hospitals need to start buying domestically produced beds, so that China's wealth can be redistributed within the country. As of now the wealth within the health care industry is being exported to Japan and the United States for equipment that China is capable of producing domestically. Our bed is just one step that will allow China to begin producing its own quality medical equipment. If this equipment is domestically produced it will allow quality healthcare to become more affordable and accessible to many Chinese citizens.

Our bed design has been designed with influence from current hospital bed products. Our bed also offers additional features to the beds that are currently used in Chinese hospitals and manufactured in China. Our bed can easily articulate the back, upper, and lower legs, as well as adjust the bed height. Our bed has been shown to be of higher quality that what is currently domestically produced within China, and of the same quality as the Paramount Bed from Japan. Aside from having more features then the other beds it will allow rural, smaller, and less wealthy hospitals to afford and implement modern healthcare equipment.

Our team feels that with a minimal amount of additional work this bed design would be an economical and effective alternative to the beds that are currently being used in China. A working prototype of the lower leg mechanism must be manufactured and tested. Additionally work must be done in the manufacturing area of the design. Appropriate material must be selected for each part and a complete prototype of this bed design must be constructed. Our team feels that these steps would be worth perusing and that this bed design would allow for the continued expansion of China's developing health care industry.

Appendix A: Existing American Bed Models

This section addressed existing American beds provided primarily by the two largest companies, Hill-Rom and Stryker Medical

TotalCare® Bed System

Our most fully-featured bed helps keep caregivers and patients safe in high-acuity environments.

Caregiver safety

- The FullChair® feature allows a single caregiver to safely and efficiently position a patient "up in chair"
- The Chair Egress feature increases patient mobility and helps minimize the risk of injury to patients and caregivers
- Shearless Pivot® mechanism and FlexAfoot™ retractable foot mechanism help minimize the need for patient repositioning
- Intellidrive® power transport allows a single caregiver to move the bed throughout the facility
- In-bed scale allows a single caregiver to weigh a patient without transport
- Turn Assist feature (offered in TotalCare SpO$_2$RT® System) facilitates easier and more efficient patient handling reduces the likelihood for injury to the caregiver
- Rotation and Percussion and Vibration Therapy-on-Demand® Modules (offered in TotalCare SpO$_2$RT System) provide enhanced caregiver productivity and improved compliance

Patient safety

- The Chair Egress System increases patient mobility and reduces the likelihood for injury to patients exiting the bed
- FlexAfoot™ retractable foot mechanism provides pressure relief to the patient's heel and minimizes patient migration to the foot of the bed
- Point-of-Care® safety controls minimize the risk of accidental activation of bed functions

VersaCare® Bed System

With the lowest height of any acute care bed, the VersaCare bed offers increased safety to caregivers and patients in medical/surgical areas.

Caregiver safety

- LowChair® feature helps to get patients "up in chair," reducing transfers and helping patients exit on their own
- FlexAfoot™ retractable foot mechanism reduces patient migration down the bed
- Non-moving headboard remains at ergonomic height during all bed articulations and may reduce caregiver injury
- Turn Assist feature (offered with VersaCare A.I.R.™ surface) assists patient repositioning
- Max Inflate (offered with VersaCare A.I.R.™ surface) creates a firm surface for patient transfers
- Optional built-in scale eliminates the need for sling scale procedures helping improve caregiver safety
- Optional IntelliDrive® power transport makes the bed easy for a single caregiver to move

Patient safety

- Ultra-low height helps reduce the risk and impact of patient falls
- Firm mattress perimeter helps patients get in and out of bed safely
- Minimized siderail gaps reduce opportunities for entrapment
- Optional Patient Position Monitor (PPM) – Three Mode Bed Exit System, with different sensitivities, tone and volume, combined with falls prevention protocols, can help to reduce patient falls
- FlexAfoot™ feature helps prevent footdrop
- Nightlight – The long-lasting LED light illuminates the area for safer patient egress
- Obstruction detection – Perimeter based light beam; reverses downward motion when beam is broken to minimize risk of patient injury
- "Bed not down" indicator helps a caregiver know when the bed needs to go lower, in order to be safer for patient egress/ingress
- OnSite™ technology – Provides information about bed features designed for patient safety to networked PC's for alerting or protocol management

CareAssist® ES Bed

The CareAssist ES bed sets a new standard for patient and caregiver safety. Dozens of design innovations, from improved braking, enhanced patient positioning, and easier-to-use controls, make this bed the value choice.

Caregiver safety

- One-button Dining Chair® moves patient in and out of chair position, and maintains a low, safe height while putting patient in a chair position
- Easy-to-read Line-of-Site® angle indicators for degree of head articulation and Trend/Reverse Trend reduces the need to bend down low
- Optional built-in scale eliminates the need for sling scale procedures helping improve caregiver safety
- Non-moving headboard remains at ergonomic height during all bed articulations and may reduce caregiver injury
- Electric vascular foot provides the ability to place patients' legs in a vascular position with the touch of a button, reducing potential for injury
- Shearless Pivot® mechanism with auto contour can reduce the need to reposition patients with the touch of a button

Patient safety

- Unique Four-Corner Brake access with audible alarm, reminds the caregiver if the brakes have not been set, to make sure the bed stays put
- Optional Patient Position Monitor (PPM) – Three Mode Bed Exit System, with different sensitivities, tone and volume, combined with falls prevention protocols, can help to reduce patient falls
- "Bed not down" indicator helps a caregiver know when the bed needs to go lower, in order to be safer for patient egress/ingress
- Nightlight – The long-lasting LED light illuminates the area for safer patient egress

Figure 29: Hill-Rom ICU and top-line Med/Surg Beds

TotalCare® Bed System. TECHNICAL DATA

Mattress
Sleeping Surface: 35" x 84"
(89 cm x 213.4 cm)

Width
Siderails up: 40" (101.6 cm)
Siderails down: 36" (91.4 cm)

Length
Without bumpers: 92" (233.7 cm)
With bumpers: 93.5" (237.5 cm)

Foot Retraction
12" (30.5 cm)

Electrical Leakage
Bed frame with air system: 50 µA

Radiolucent Window
23"L x 22"W (58.4 cm x 55.9 cm)

Height of Siderail
Above mattress: 10" (25.4 cm)
Above deck: 15" (38.1 cm)

Chair Positioning
Chair Position:
50° - 65° Head
0 - 10° Seat
30° - 70° Foot

Chair Egress Position:
65° - 75° Head
0 - 10° Seat
70° - 85° Foot

Bed Articulation
Trendelenburg / Reverse
Trendelenburg: 15°/15°
Emergency Trendelenburg:
Head Section: 75°
Knee: 20°
Automatic Contour: 10°

Caster Size
5" (12.7 cm)
1" extended "stem" (2.54 cm) available

Height
Height from floor to top of deck in low position: 17.5" (44.5 cm)
Height from floor to top of deck in high position: 36.5" (92.7 cm)

Wheelbase
42" (106.7 cm)

Wheeltrack
26" Head (65.4 cm)
23.5" Foot (59.7 cm)

Underbed Clearance
.75" (12.1 cm)

Scale
Accuracy: 1% of patient weight
Repeatability: +/- .3% 70.5 to 175 lbs. (32.0 to 79.4 kg)
+/- .1% 175 to 400 lbs. (79.4 to 181.4 kg)

Weighing Capacity:
400 lbs. (181.4 kg)
Maximum Working Load:
500 lbs. (226.8 kg)

Figure 30: Characteristics of the Hill-Rom TotalCare ICU bed

3800 E. Centre Ave.
Portage, MI 49002
t: 269 329 2100 f: 269 329 2311
toll free: 800 787 9537

www.stryker.com

Standard Features

- Fully electric three-motor bed
- Height range of 12" (30 cm) to 28" (71 cm)
- Nurse controlled drop-down caster system with in-use safety light
- Reverse floor lock system with large anti-slip leg pads
- Perforated pan surface
- Foot-end nurse controls with concealed main switch
- Side and foot-end mattress retainers
- Four IV sockets
- 76", 78", or 80" fixed-length deck available

Specifications

• **Model Number**	**FL14E1**	
• **Overall Length**		
76" Model	84"	(213 cm)
78" Model	86"	(218 cm)
80" Model	87"	(221 cm)
• **Overall Width**		
Siderails Up	42"	(107 cm)
Siderails Down	37"	(94 cm)
• **Weight Capacity**	350 lbs	(159 kg)
• **Height Range** (to litter top)		
High	28"	(71 cm)
Low	12"	(30 cm)
• **Litter Positioning**		
Backrest	0° - 60°	
Knee Gatch	0° - 30°	
• **Patient Surface**		
76" Model	35" x 76"	(89 x 193 cm)
78" Model	35" x 78"	(89 x 198 cm)
80" Model	35" x 80"	(89 x 203 cm)
• **Caster Diameter**	3"	(8 cm)

Electronics

• **Agency Approvals**	US CSA
• **Volts**	120 VAC
• **Ampere Rating**	7A
• **Current Leakage**	<100 microamperes
• **Frequency**	60 Hz
• **Hospital Grade Plug**	Yes

Figure 31: Stryker LTC Bed Features

GoBed II®
Med/Surg Bed

stryker

Medical

3800 E. Centre Ave.
Portage, MI 49002
t: 269 329 2100 f: 269 329 2311
toll free: 800 787 9537

www.stryker.com

Standard Features (GoBed II C)

- 14.5" (37 cm) low bed height
- Retractable fifth-wheel steering
- Retractable sleep surface
- 6" (15 cm) casters
- Trend./reverse Trend.
- Four independent electric motors
- Trend. display on footboard (only available with scale option)
- Centrally-located steer and four-wheel brake mechanism
- Four drainage bag hooks
- Eight IV pole/traction equipment sockets
- Roller bumpers
- Manual back up for head and knee control
- Integrated pump holder
- Nurse controls on footboard and siderails
- Fixed patient controls on siderails
- Degree indicator for head elevation
- Patient restraint locations
- Electronic function lockout controls
- One-handed dampened siderail release
- Auto contour
- Photo-sensitive night light

GoBed II LX: All Standard Features Plus

- Chaperone center-of-gravity bed exit system
- In-bed scale system
- CPR release

GoBed II EX: All Standard Features Plus

- Chaperone center-of-gravity bed exit system
- In-bed scale system
- One-button cardiac chair
- CPR release
- Siderails communications-includes nurse call with speakers, TV, radio, volume, room/read lights

Specifications

• **Model Number**	FL28C, FL28EX	
• **Overall Length**	94.25"	(240 cm)
• **Overall Width**		
Siderails Up	40"	(102 cm)
Siderails Down	39"	(99 cm)
• **Weight Capacity**	500 lbs	(226 kg)
• **Height Range** (to litter top)		
High	29"	(74 cm)
Low	14.5"	(37 cm)
• **Litter Positioning**		
Backrest	0° - 60°	(siderails down)
Knee Gatch	0° - 28°	
Trend./reverse Trend.	±14°	
Retraction	10"	(25 cm)
• **Patient Surface**	36" x 84"	(91 x 213 cm)
• **Caster Diameter**	6"	(15 cm)

Electronics

• **Agency Approvals**	
Domestic	UL60601-1
International	CSA601.1 and IEC60601-2-38
• **Volts**	
Domestic	120 VAC
International	100 VAC, 120 VAC, 200 VAC, 220 VAC
• **Ampere Rating**	
Domestic	4A, 9.8A with auxilary outlet
International	100 VAC-7.5A, 200 VAC-3.2A, 220 VAC-2.9A, 240 VAC-2.7A
• **Current Leakage**	<100 microamperes
• **Frequency**	50-60 Hz
• **Hospital Grade Plug**	Yes

Stryker reserves the right to change specifications without notice.

Optional Features

- Chaperone center-of-gravity bed exit system
- Chaperone with Zone Control®
- In-bed scale system
- CPR release
- Smart TV-includes channel up/down
- Mattresses: management and prevention
- Bed extender with pad
- Pillow speaker interface
- Removable litter covers
- Upright oxygen bottle holder
- IV poles
  - Permanent
  - Removable
- 110-volt power outlet
- Patient helper system
- Emergency crank handle
- Footboard-mounted monitor tray

Figure 32: Stryker GoBedII Specifications and Features

EPIC II®
Critical Care Bed

stryker®

Medical

3800 E. Centre Ave.
Portage, MI 49002
t: 269 329 2100 f: 269 329 2311
toll free: 800 787 9537

www.stryker.com

Standard Features

- Siderail and footboard positioning controls
  - Cardiac chair, emergency drop
  - Backrest/Trend. angle display
  - High/low, Trend./reverse Trend.
- Radiolucent from neck through pelvic region
- Scale-isolated drainage bag hooks/head-end IV poles
- Integrated 8" (20 cm) bed extender
- Four-wheel, steel-ring brake system with centrally-located activation pedals
- 90° backrest for upright chest imaging
- Dual pedestal design
- CPR release for backrest and knee
- 6" (15 cm) casters
- Locking-caster steering
- Four traction sockets
- Four IV receptacles (scale isolated at head end)
- Electric function lock-out controls
- In-rail backrest/knee gatch controls
- Removable CPR board

Specifications

• **Model Number**				
Domestic	**2030** (115 VAC)		**2040** Zoom Drive	
International	**2031** (230 VAC)			
• **Overall Length**	91"	(231 cm)	93"	(236 cm)
• **Overall Width**				
Siderails Up	42.5"	(108 cm)	42.5"	(108 cm)
Siderails Down	40"	(102 cm)	40"	(102 cm)
• **Weight Capacity**	500 lbs	(228 kg)	500 lbs	(228 kg)
• **Standard Height Range** (to litter top)				
High	32.5"	(83 cm)	32.5"	(83 cm)
Low	18"	(46 cm)	18"	(46 cm)
• **Optional Enhanced Fluoro Height Range** (to litter top)				
High	34.5"	(88 cm)	N/A	
Low	19.5"	(50 cm)	N/A	
• **Litter Positioning**				
Backrest	0° - 90°		0° - 90°	
Knee Gatch	0° - 30°		0° - 30°	
Trend./reverse Trend.	±12°		+10/-12°	
• **Patient Surface**	35" x 84"	(89 x 213 cm)	35" x 84"	(89 x 213 cm)
• **Caster Diameter**				
Standard	6"	(15 cm)	6"	(15 cm)
Optional	8"	(20 cm)	N/A	

Electronics

• **Agency Approvals**	C-US UL (2030), CE (2031)	C-US UL (2040)
• **Volts**	115 VAC (Domestic)/230VAC (International)	115 VAC / 24 VDC (Zoom Drive)
• **Ampere Rating**	7A (Domestic) /4A (International)	7A
	5A (rating for 115 volt outlet option)	5A (rating for 115 volt outlet option)
• **Current Leakage**	<100 microamperes	<100 microamperes
• **Frequency**	60 Hz (Domestic)/50-60 Hz (International)	60 Hz
• **Hospital Grade Plug**	Yes	Yes

Stryker reserves the right to change specifications without notice.

Optional Features

- Zoom® Motorized Drive System
- In-bed scale system
- Chaperone® center-of-gravity bed exit system
- Chaperone with Zone Control®
- Battery backed-up motion controls
- Siderail communications—includes nurse call with speaker, TV, radio, volume, room/read lights
- Smart TV—includes closed caption, channel up/down and mute
- Mattresses: management and prevention
- Bed extender pad
- Removable CPR board
- Defibrillator tray
- Backrest/X-ray cassette holder
- Pendant control
- Pillow speaker interface
- Pump holder mount on footboard
- Siderail pads
- Transducer mounts—siderail and IV pole
- Traction sleeve adapter kits
- Upright oxygen bottle holder
- Wallsaver™ quick-release connecting kit
- 8"(20 cm) Omni Surface™ casters with wheel covers
- IV poles
  - Dual head-end folding
  - Permanent folding two-stage
  - Removable

LSS-453-04D
PC-SCG-7.5M-0306
Mkt Lit-76-02022005 Rev D

Figure 33: Stryker Epic II Features and Specifications

Secure II®
Med/Surg Bed

stryker®

Medical

3800 E. Centre Ave.
Kalamazoo, Mich. 49001 USA
t: 269 329 2100 f: 269 329 2311
toll free: 800 787 9537

www.stryker.com

Standard Features

- 6" (15 cm) casters
- Dual pedestal design
- CPR release
- In-rail fowler/knee gatch control
- Electronic function lock-out control
- Four-wheel, steel-ring brake system with centrally-located activation pedals
- Backrest angle indicator
- Locking-caster steering
- Four traction sockets
- Removable headboard with CPR capability
- Retractable litter top
- Four foley bag hooks
- Four IV receptacles
- Patient restraint locations
- Trend./reverse Trend. controls

EX Model: All Standard Features Plus

- Chaperone® center-of-gravity bed exit system
- Scale with isolated foley bag hooks and Trend. display
- Stryker pendant port

ZX Model: EX Features Plus

- Zoom® Motorized Drive System

Specifications

• **Model Number**		
Domestic	**3002** (115 VAC)	
International	**3221** (230 VAC)	
• **Overall Length**	93"	(236 cm)
• **Overall Width**		
Siderails Up	42.5"	(108 cm)
Siderails Down	40"	(102 cm)
• **Weight Capacity**	500 lbs	(228 kg)
• **Height Range** (to litter top)		
High	30"	(76 cm)
Low (standard with 6" casters)	16"	(41 cm)
Low (ZX option)	19.75"	(50 cm)
• **Litter Positioning**		
Backrest	0° - 60°	
Knee Gatch	0° - 40°	
Trend./reverse Trend.	±12° (± 10° with ZX option)	
Retraction	14"	(36 cm)
• **Patient Surface**	35" x 84"	(89 x 213 cm)
• **Caster Diameter**		
Standard	6"	(15 cm)
Optional	8"	(20 cm)

Electronics

• **Agency Approvals**	C-US UL (3002), CE (3221)
• **Volts**	115 VAC (Domestic) / 230 VAC (International)
• **Ampere Rating**	7A (Domestic) / 4A (International) 10A (rating for 115 volt outlet option)
• **Current Leakage**	<100 microamperes
• **Frequency**	60 Hz (Domestic) / 50-60 Hz (International)
• **Hospital Grade Plug**	Yes

Stryker reserves the right to change specifications without notice.

Optional Features

- In-bed scale system
- Chaperone center-of-gravity bed exit system
- Chaperone with Zone Control®
- Siderail communications—includes nurse call with speaker, TV, radio, volume, room/read lights
- Smart TV—includes closed caption, channel up/down and mute
- Mattresses: management and prevention
- Adapter bracket for patient helper (not available with Zoom)
- Bed extender
- Removable CPR board
- Defibrillator tray
- Pendant control
- Pillow speaker interface
- Pump holder mount on footboard
- Siderail pads
- Transducer mount—siderail or IV pole
- Traction sleeve adapter kits
- Upright oxygen bottle holder
- Wallsaver™ quick-release connecting kit
- 8" (20 cm) Omni Surface™ casters with wheel covers
- IV poles
  - Permanent folding two-stage
  - Removable
- 110 volt power outlet (not available with Zoom)
- Prop rod

LSS-453-06D
PC-SCG-5M-1005
Mkt Lit-78-02022005 Rev D

Figure 34: Stryker Secure II Features and Specification

Appendix B: Hospital Bed Design Matrices

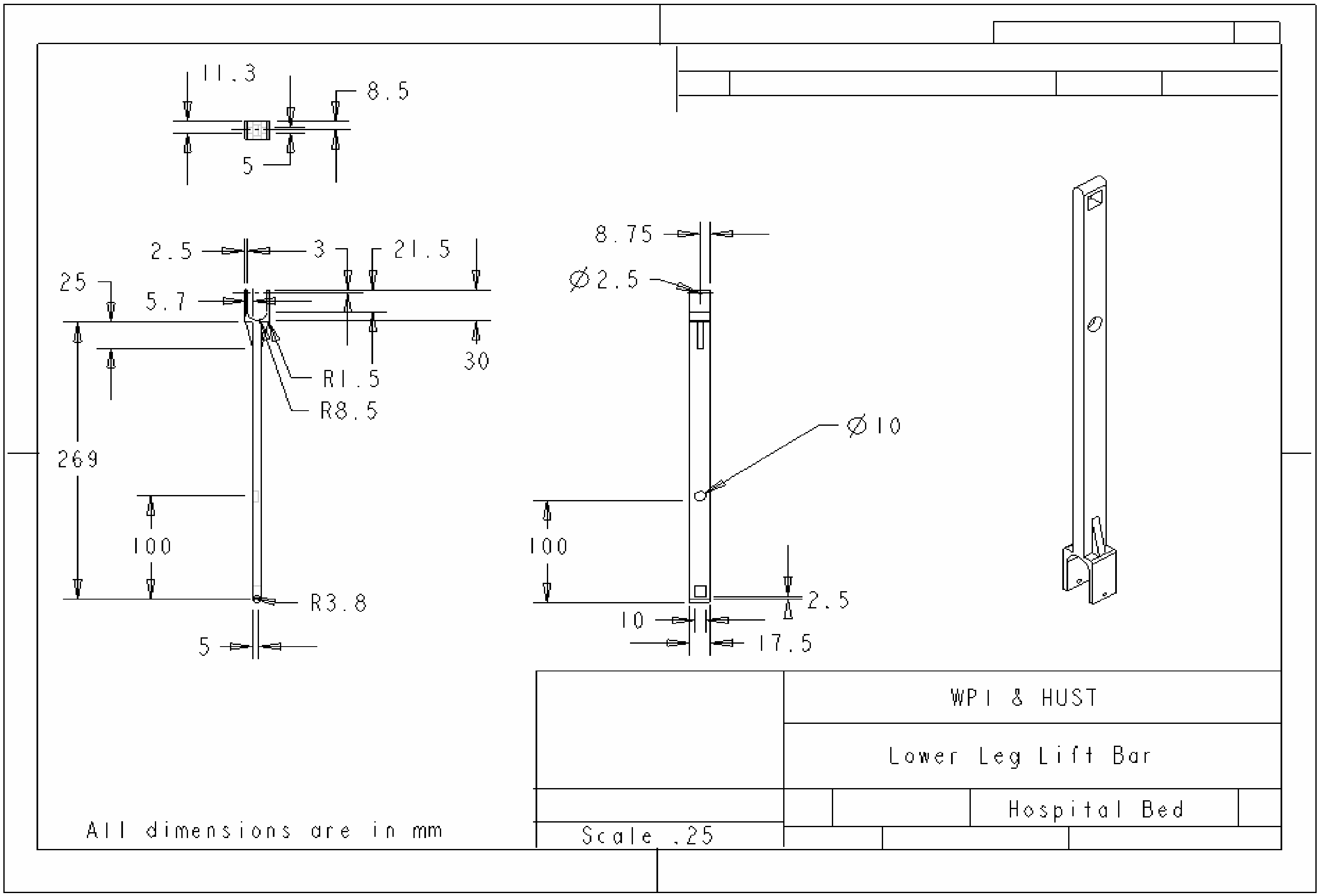
This section shows two matrices; the first which has a comparison of the beds we found in our background research and the second is a similar matrix but it also includes the bed our own group designed for analysis.

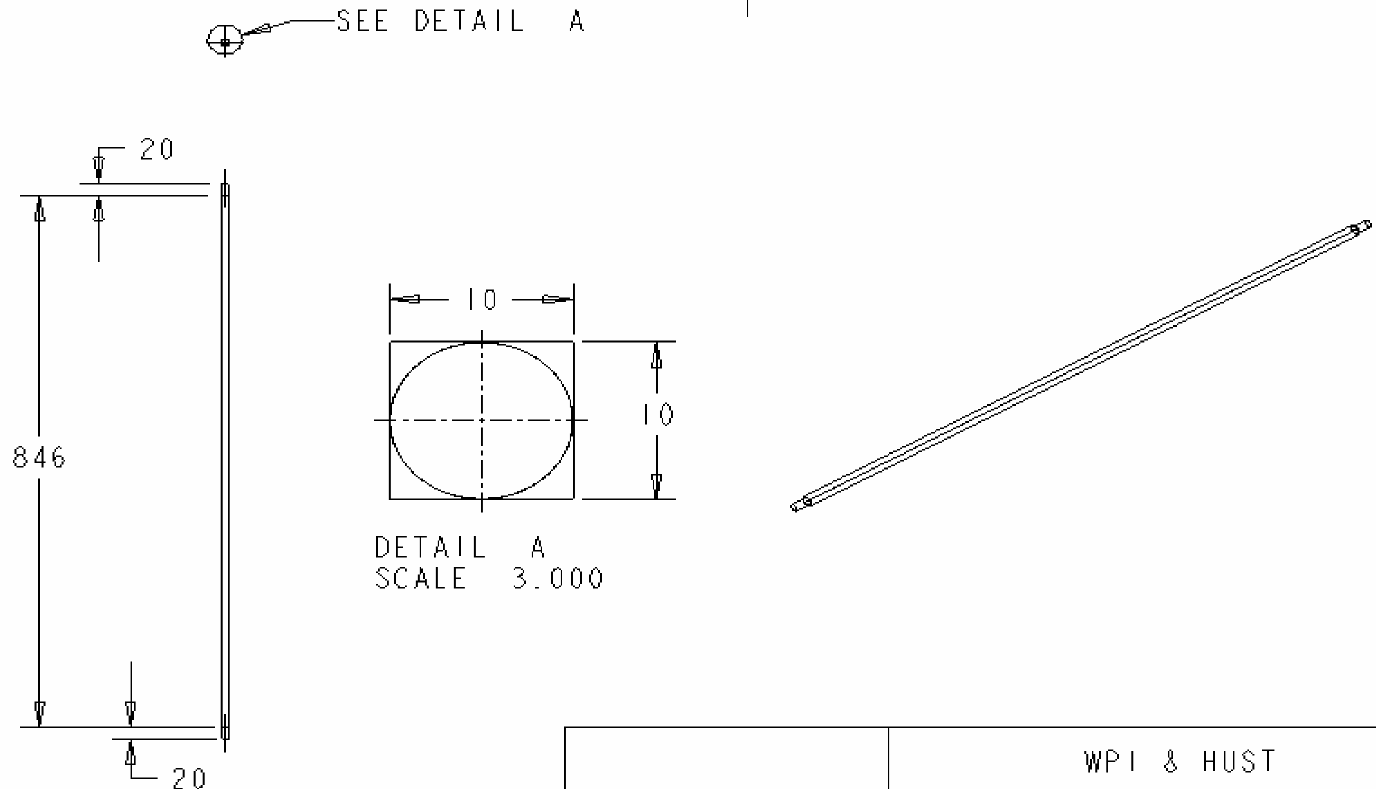
Scores scaled from 1-10	**Stryker Epic II ICU**	**Stryker GoBed II Med/Surg**	**Stryker Secure II Med/Surg**	**Stryker LTC Med/Surg**	**HillRom Total Care ICU**	**Hill-Rom VersaCare Med/Surg**	**Hill-Rom CareAssist Med/Surg**	**Hill-Rom Century+ Med/Surg**	**Paramount Bed**	**Wuhan made Med-Surg**
Curatorial Industry Standards (20%)	8	8	7	8	7	9	9	9	10	10
Durability (15%)	7	7	8	9	9	7	8	9	8	3
Safety (15%)	10	10	9	9	10	8	8	9	7	4
Ease of Manufacturing (12%)	2	3	5	9	1	3	5	8	10	10
Cost (12%)	1	4	6	8	1	3	5	8	6	10
Ease of Operation (10%)	7	8	8	10	8	8	9	10	5	4
Ease of Transportation (5%)	10	6	6	7	3	6	6	6	6	4
Leg Mobility (5%)	10	8	8	2	10	8	8	2	7	2
Electric Functions (4%)	10	10	10	5	10	10	10	5	0	0
Additional Patient Functions (2%)	10	8	7	6	10	9	8	6	0	0
Total Score	7.61	7.69	7.87	8.59	7.34	7.57	8.2	8.62	7.32	6.15

Table 3: Design Matrix of Existing Bed Models

Appendix C: Orthographic Drawings for the Lower Leg Lifting Mechanism

Appendix C displays all orthographic drawings that were designed using the ProE/Wildfire software for the lower leg lifting mechanism, a first of its kind as far as any of us were able to determine in our research. Each piece is appropriately labeled and designed showing the 2-D views as well as a 3-D view for further reference.





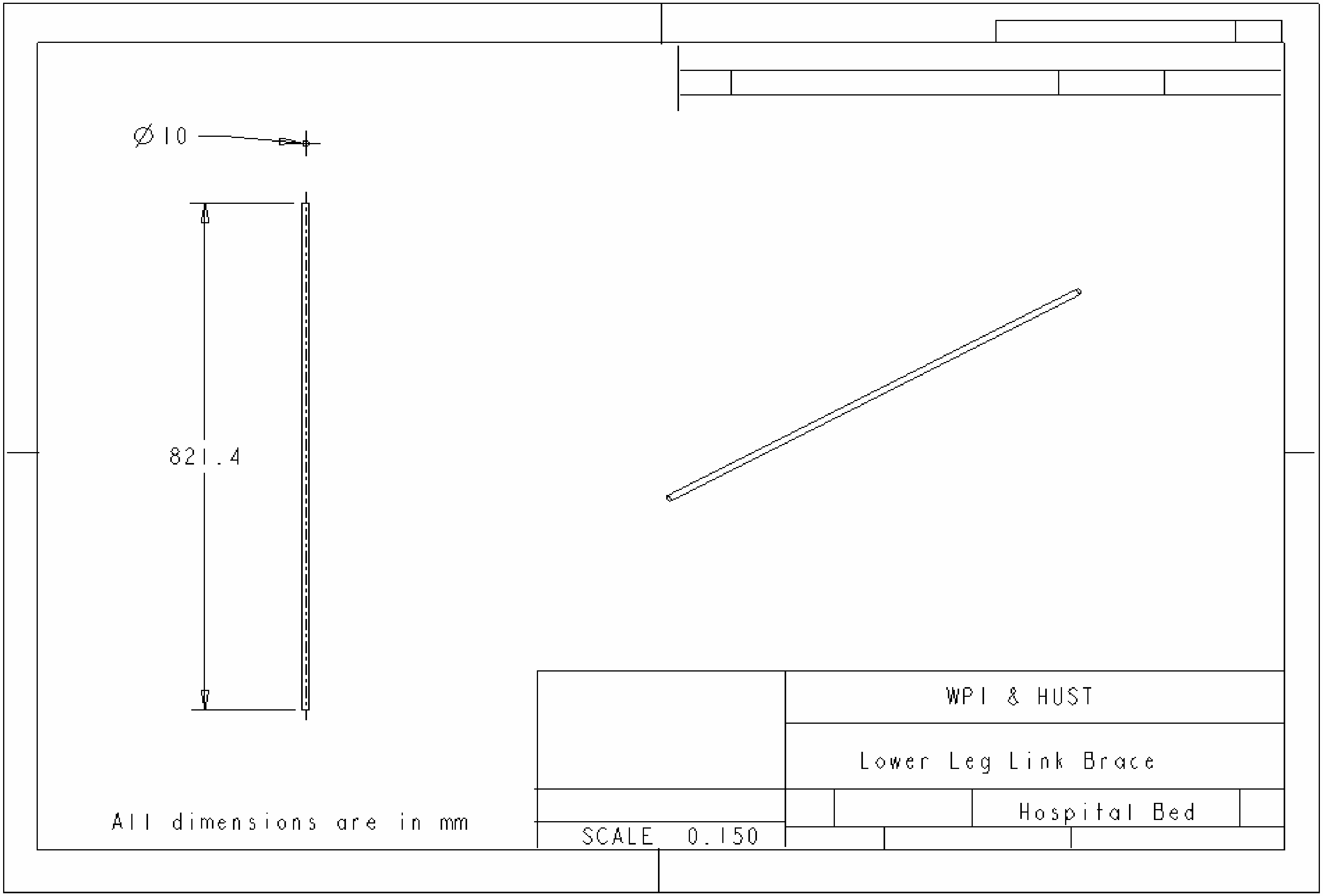
All dimensions are in mm

SCALE 0.120

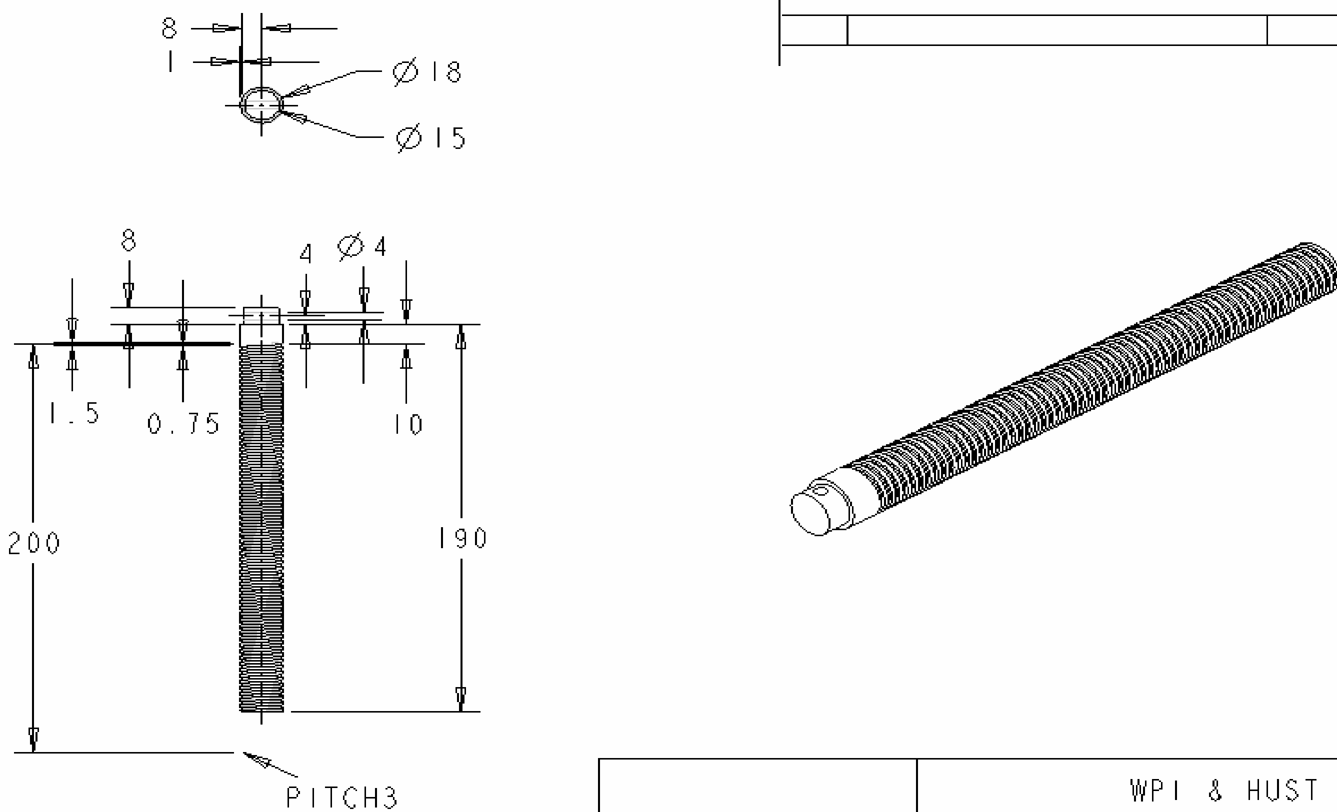
WPI & HUST

Lower Leg Link Bar

Hospital Bed



Ø10
821.4
All dimensions are in mm
SCALE 0.150
WPI & HUST
Lower Leg Link Brace
Hospital Bed



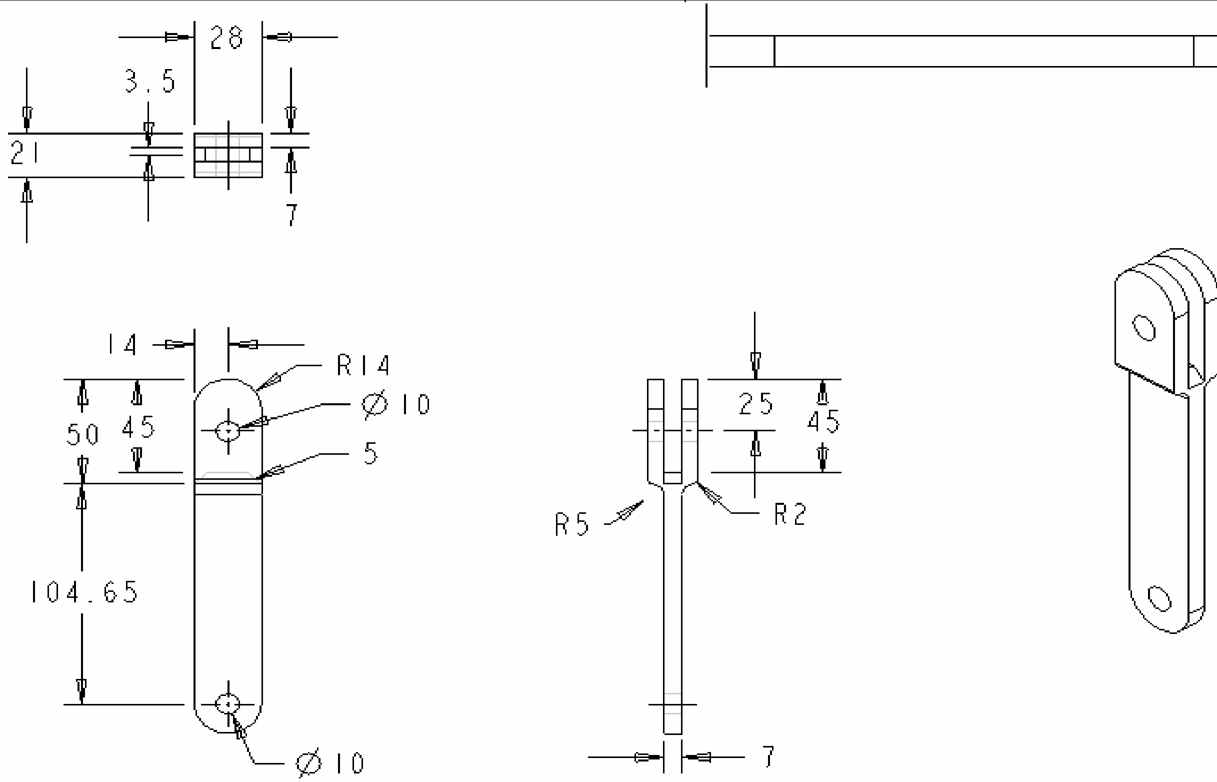
All dimensions are in mm

SCALE 0.400

WPI & HUST

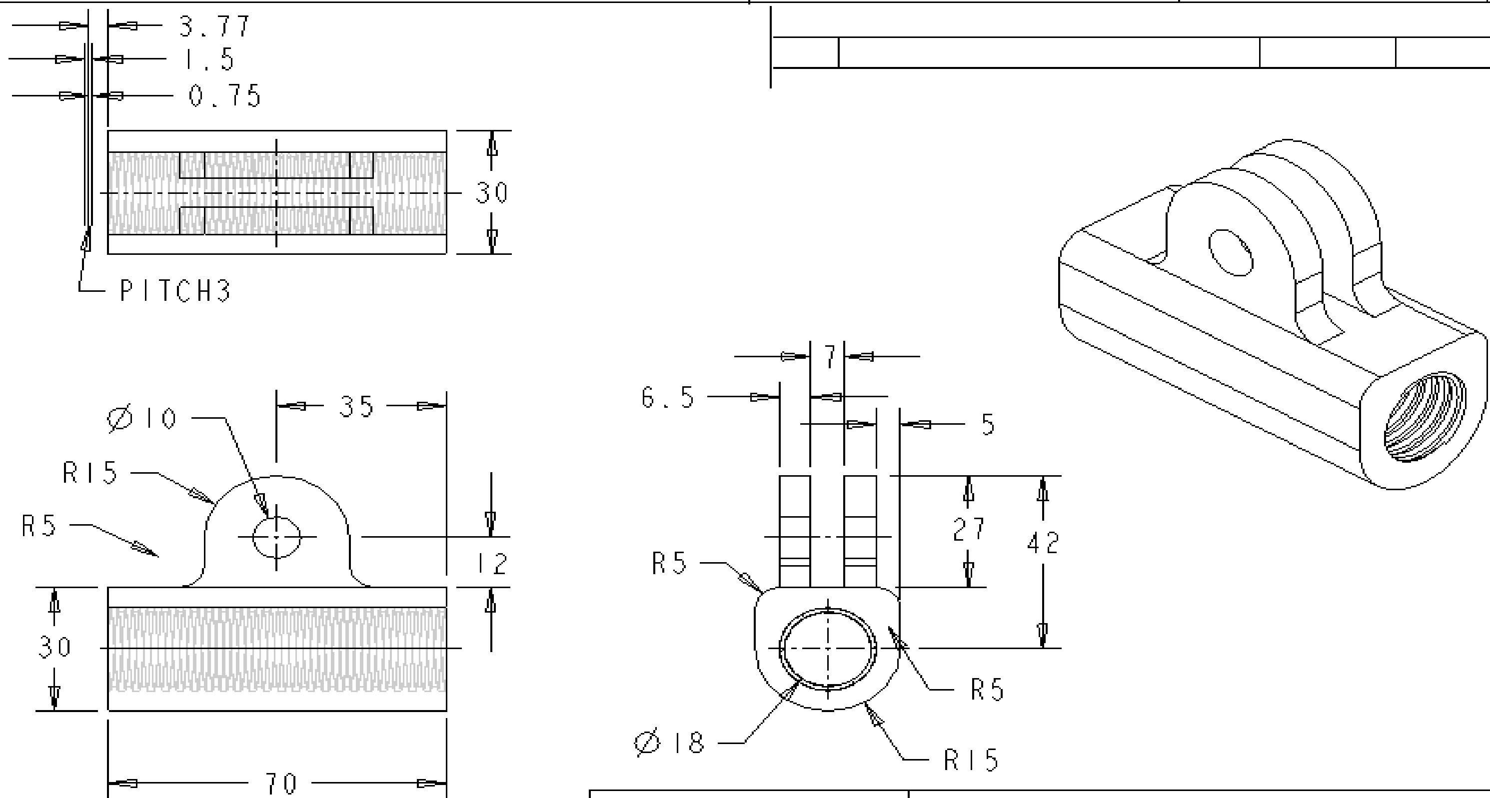
Screw For Lower Leg Link

Hospital Bed



	WPI & HUST
	Lower Leg Support Bar
SCALE 0.400	Hospital Bed

All dimensions are in mm

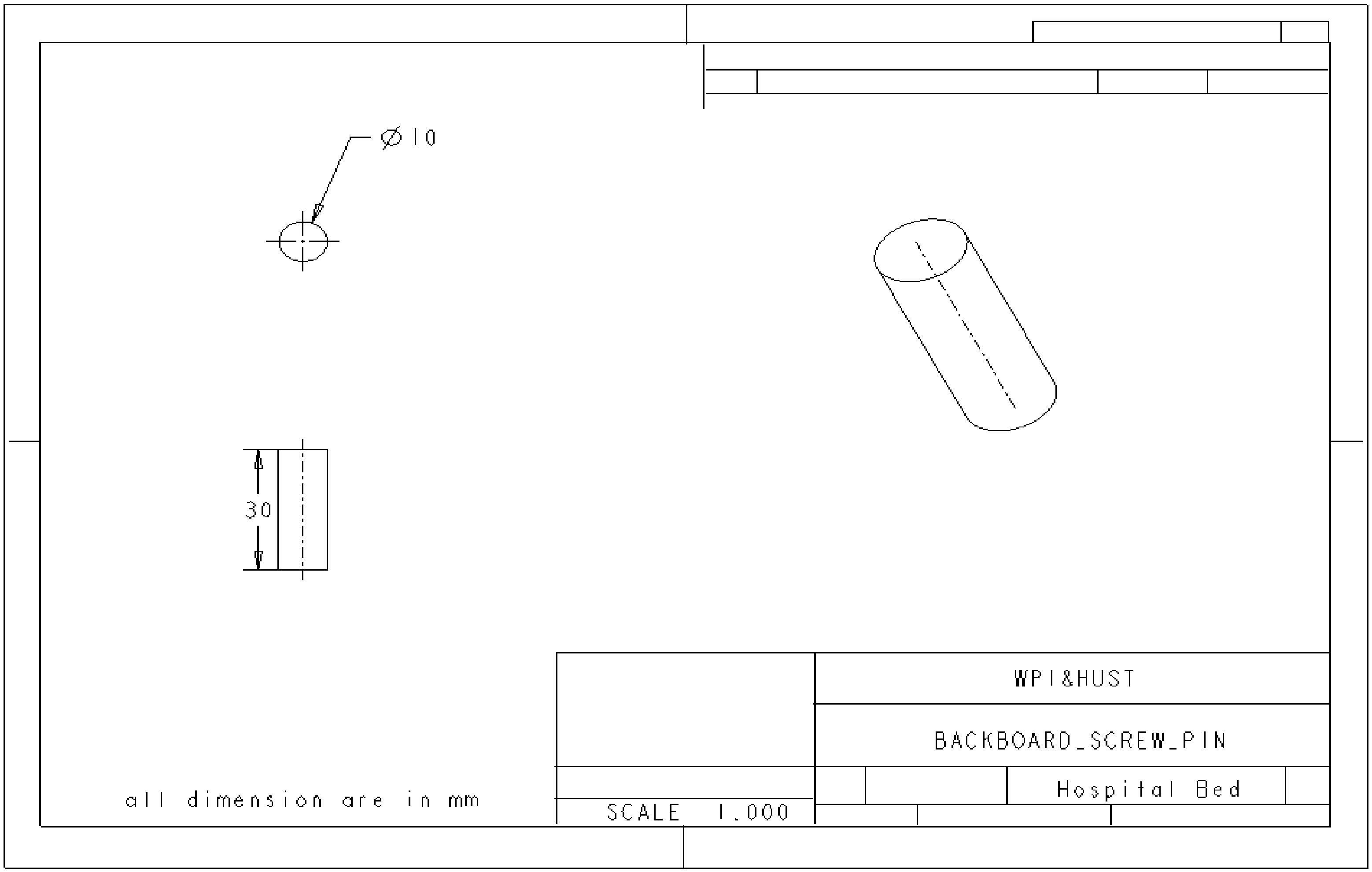


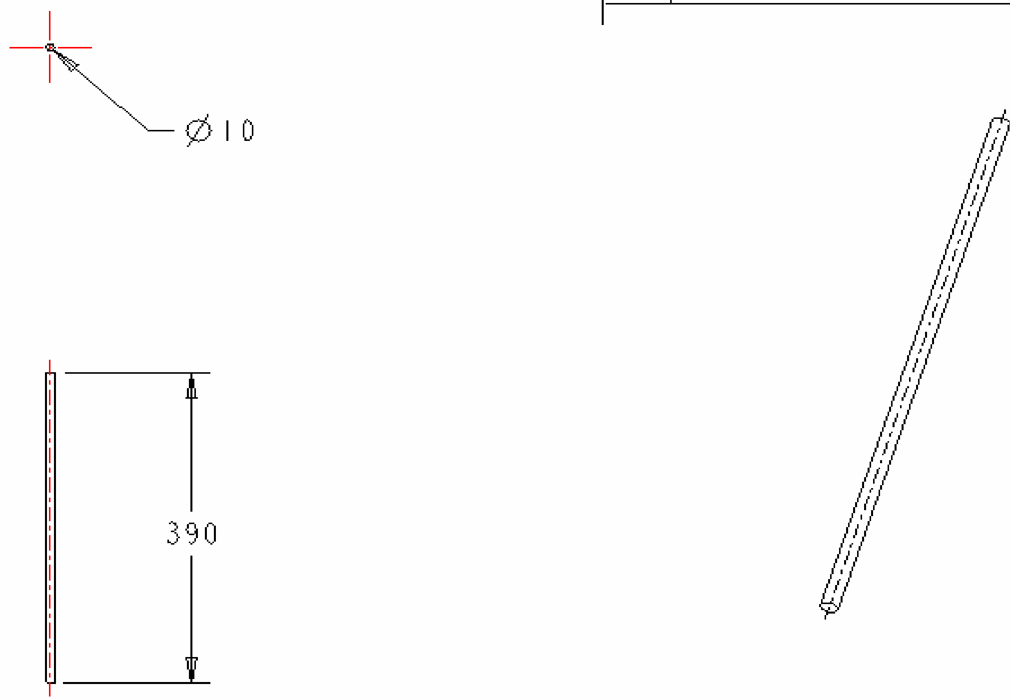
All dimensions are in mm

	WPI & HUST
	Lower Leg Link Slider
SCALE 0.800	Hospital Bed

Appendix D: Other Orthographic Drawings

Similar to Appendix C, the Appendix D shows all other components of the bed designed in ProE/Wildfire





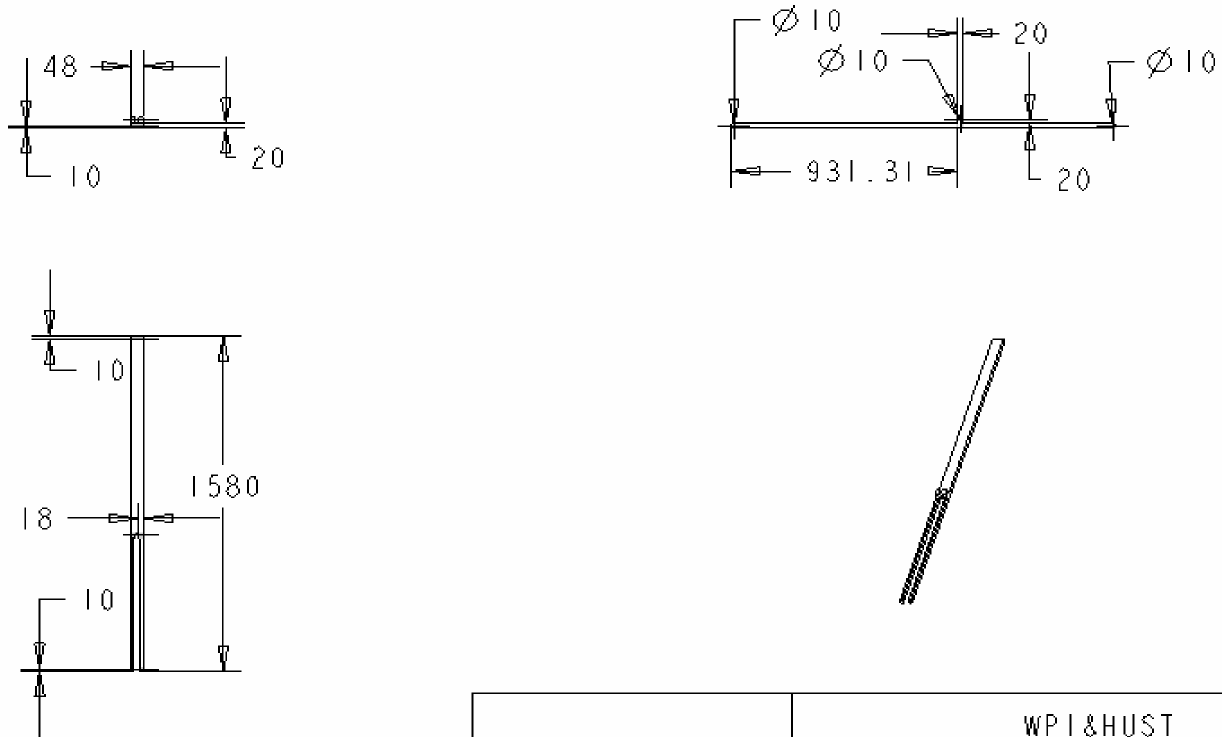
WPI&HUST

BACKBRACE

Hospital Bed

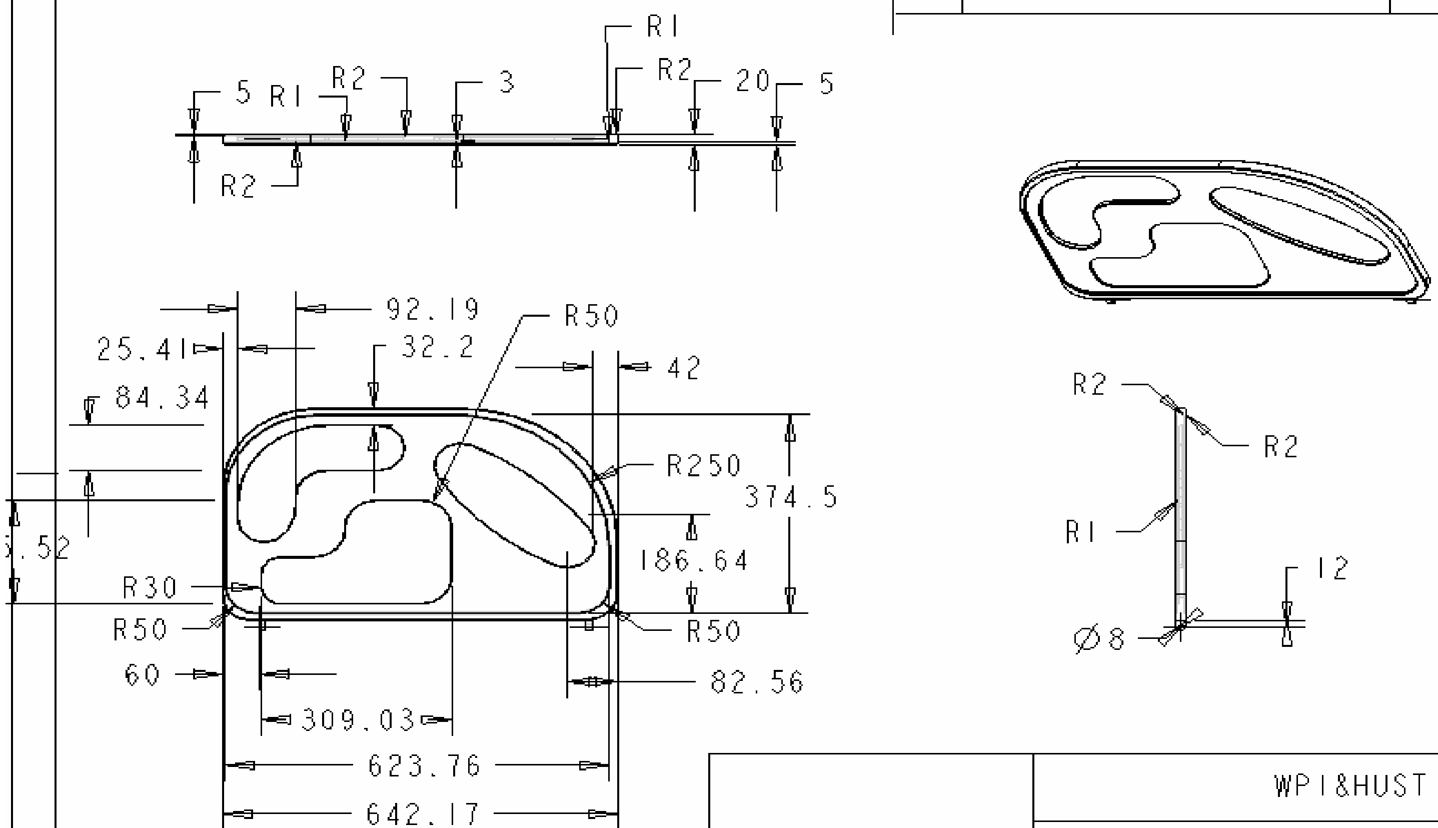
SCALE 0.150

all dimension are in mm



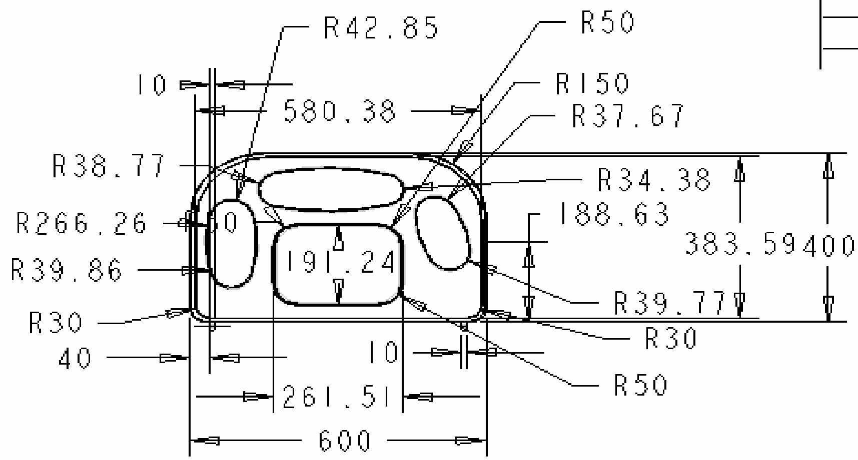
all dimension are in mm

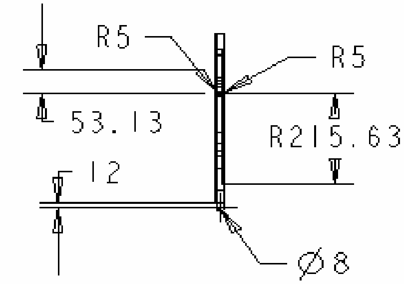
	WPI&HUST
	BED_RAISING_SUPPORT_BAR
	Hospital Bed
SCALE 0.040	

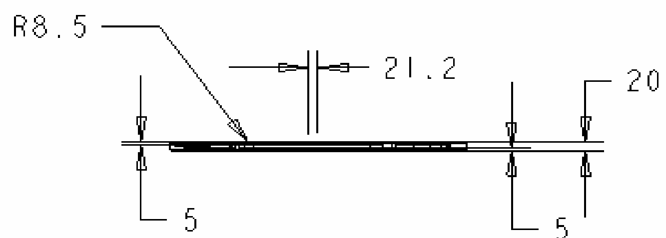


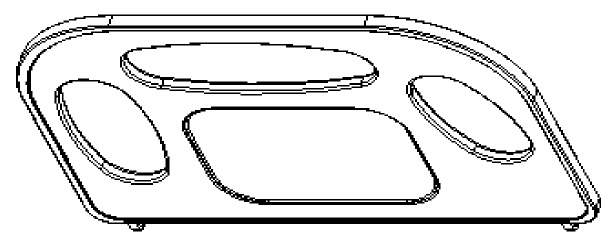
all dimension are in mm

	WPI&HUST
	BEDRAIL-FOOT
SCALE 0.100	Hospital Bed



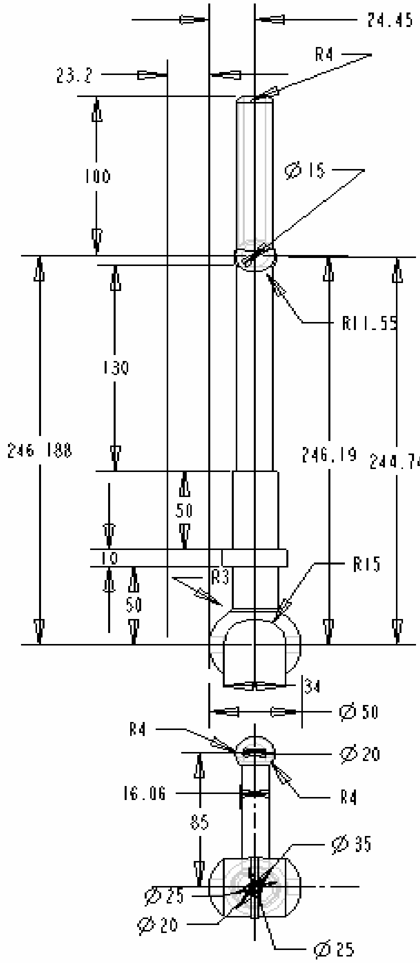


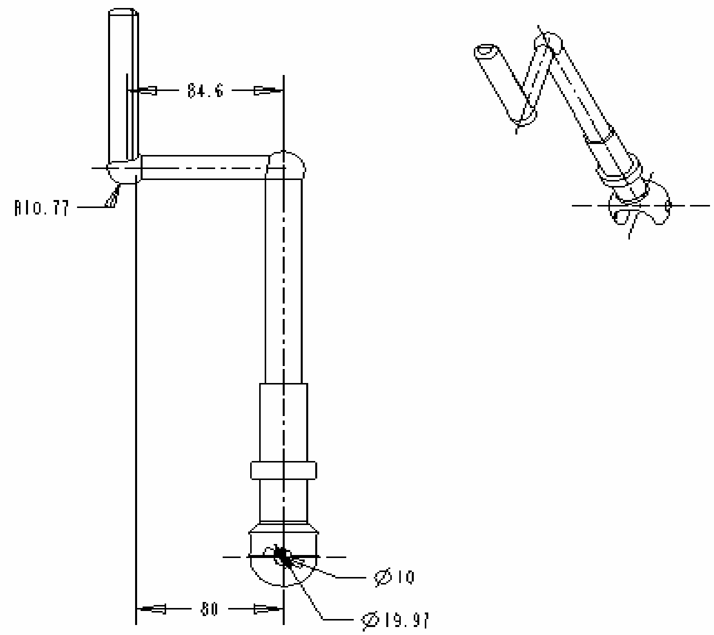




all dimension are in mm

	WPI&HUST
	EBDRAIL-HEAD
SCALE 0.080	Hospital Bed





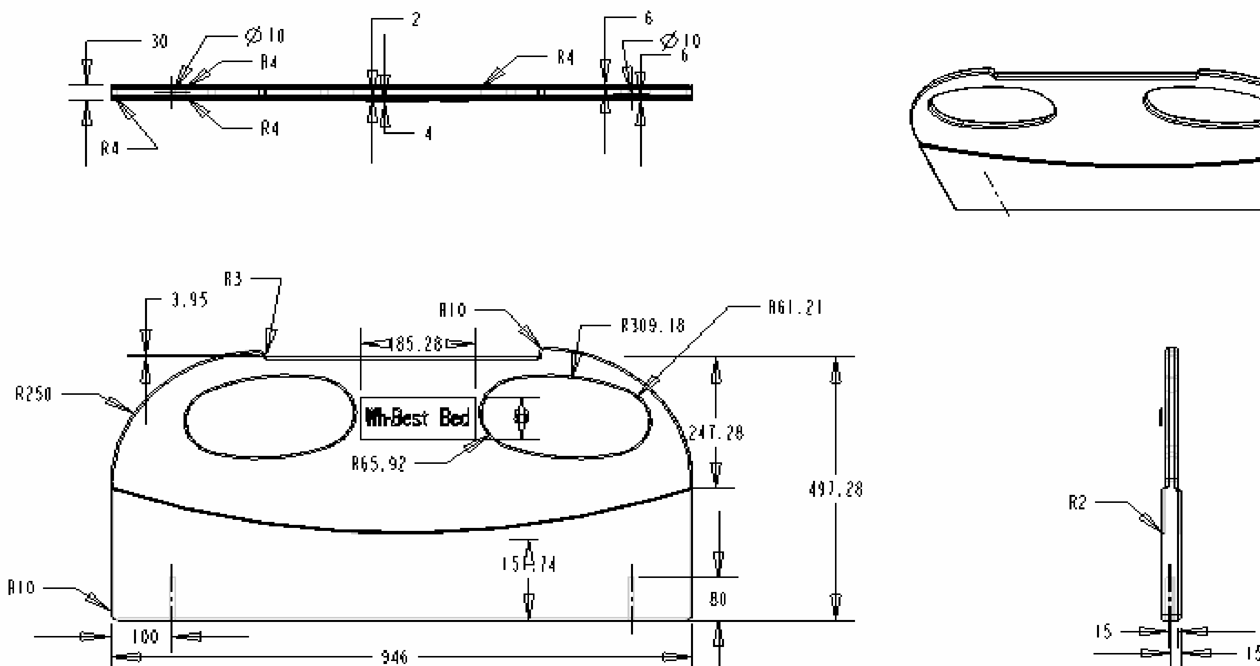
All dimensions are in mm

HSUT & WPI

COUPLING

Hospital Bed

SCALE 0.3



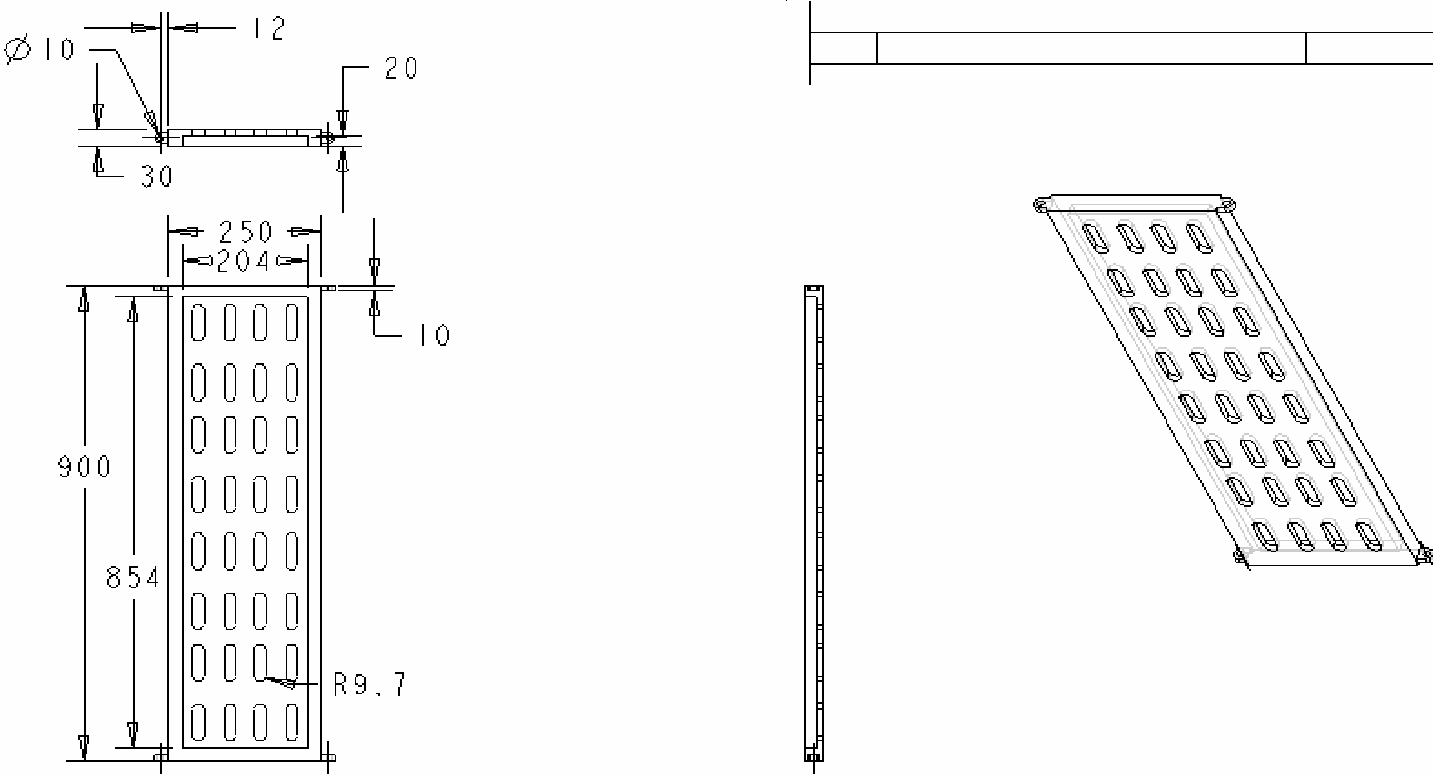
All dimensions are in mm

WPI & HUST

FOOTBOARD

Hospital Bed

SCALE 1.0



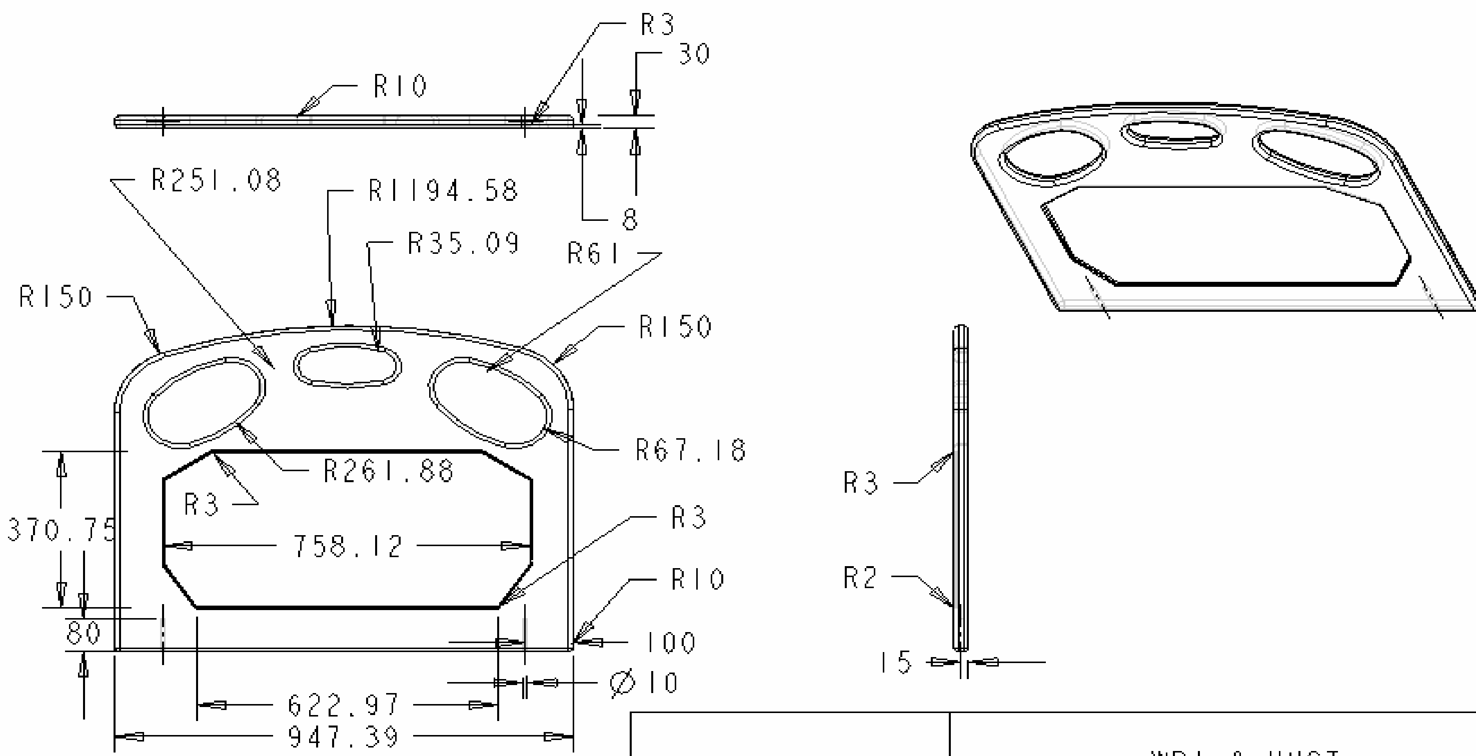
All units are in mm

WPI & HUST

GLUTEUSBOARD

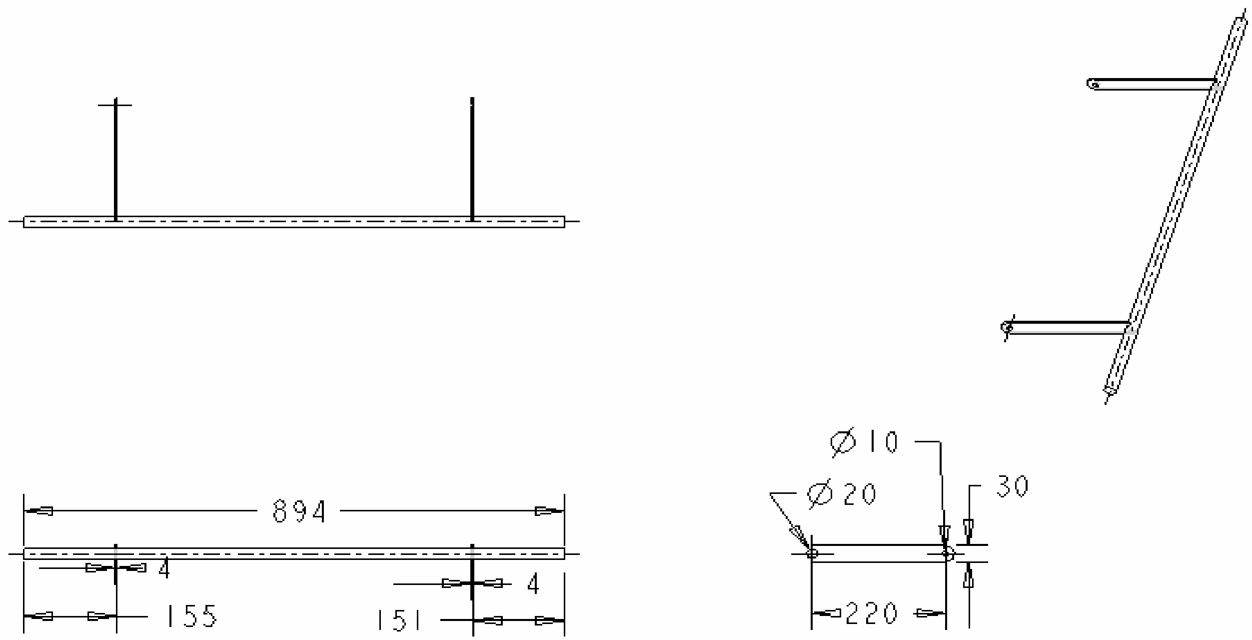
Hospital Bed

Scale .100



All units are in mm

	WPI & HUST
	HEADHOARD
	Hospital Bed
SCALE 0.08	



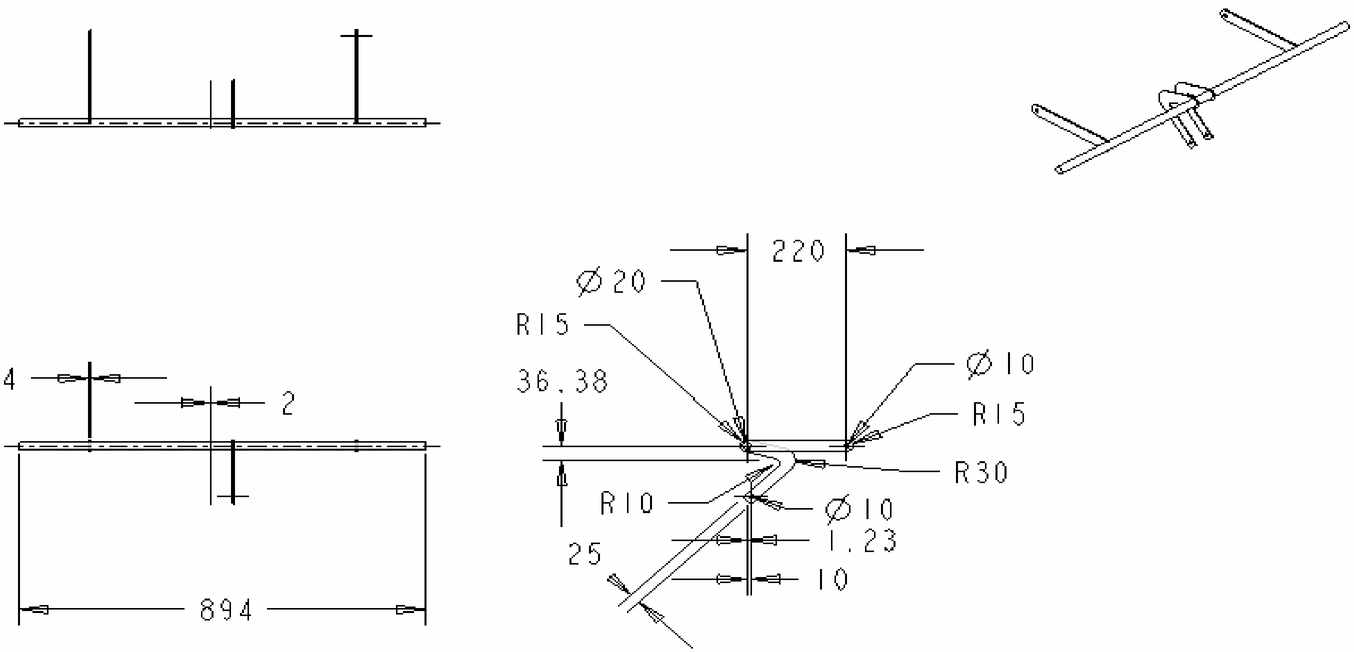
All units are in mm

SCALE 0.1

WPI&HUST

PARALLELOGRAM-ABOVE

Hospital Bed



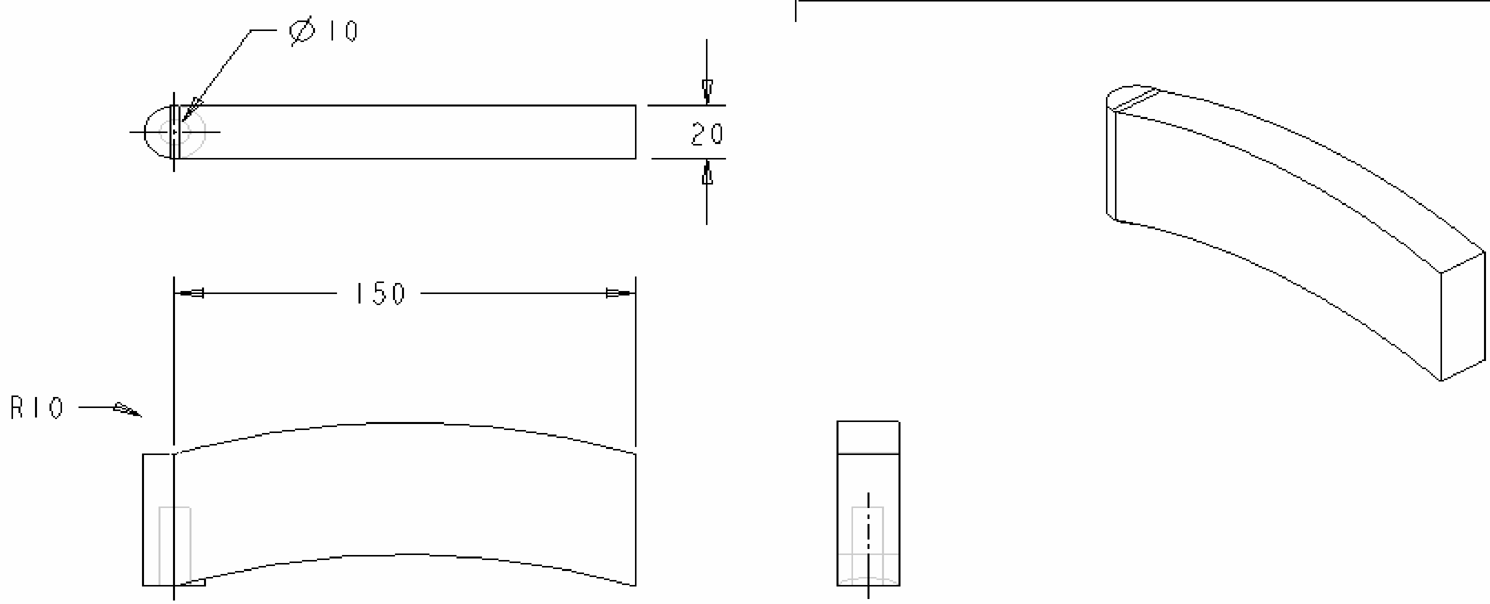
WPI & HUST

Lower Parallelogram

Hospital Bed

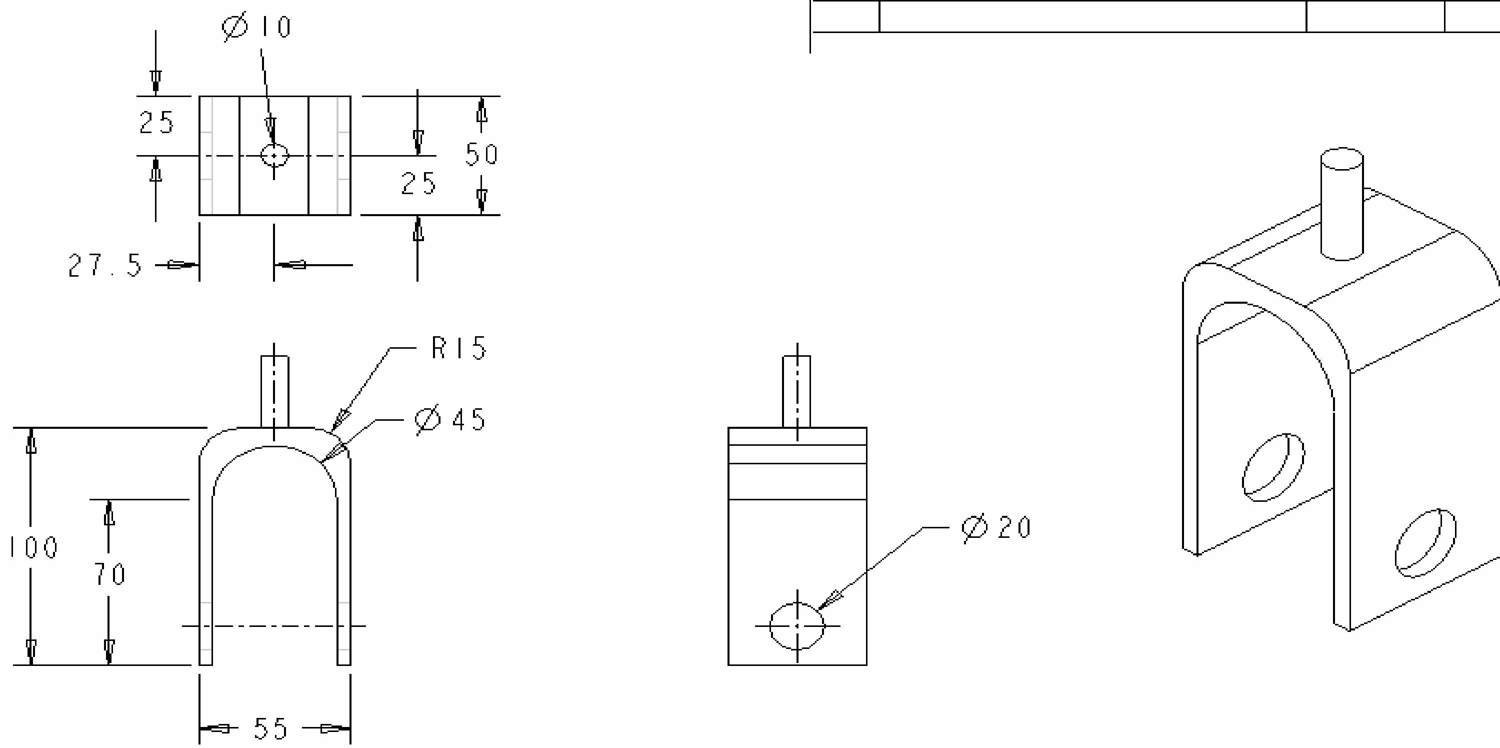
SCALE 0.075

All dimensions are in mm



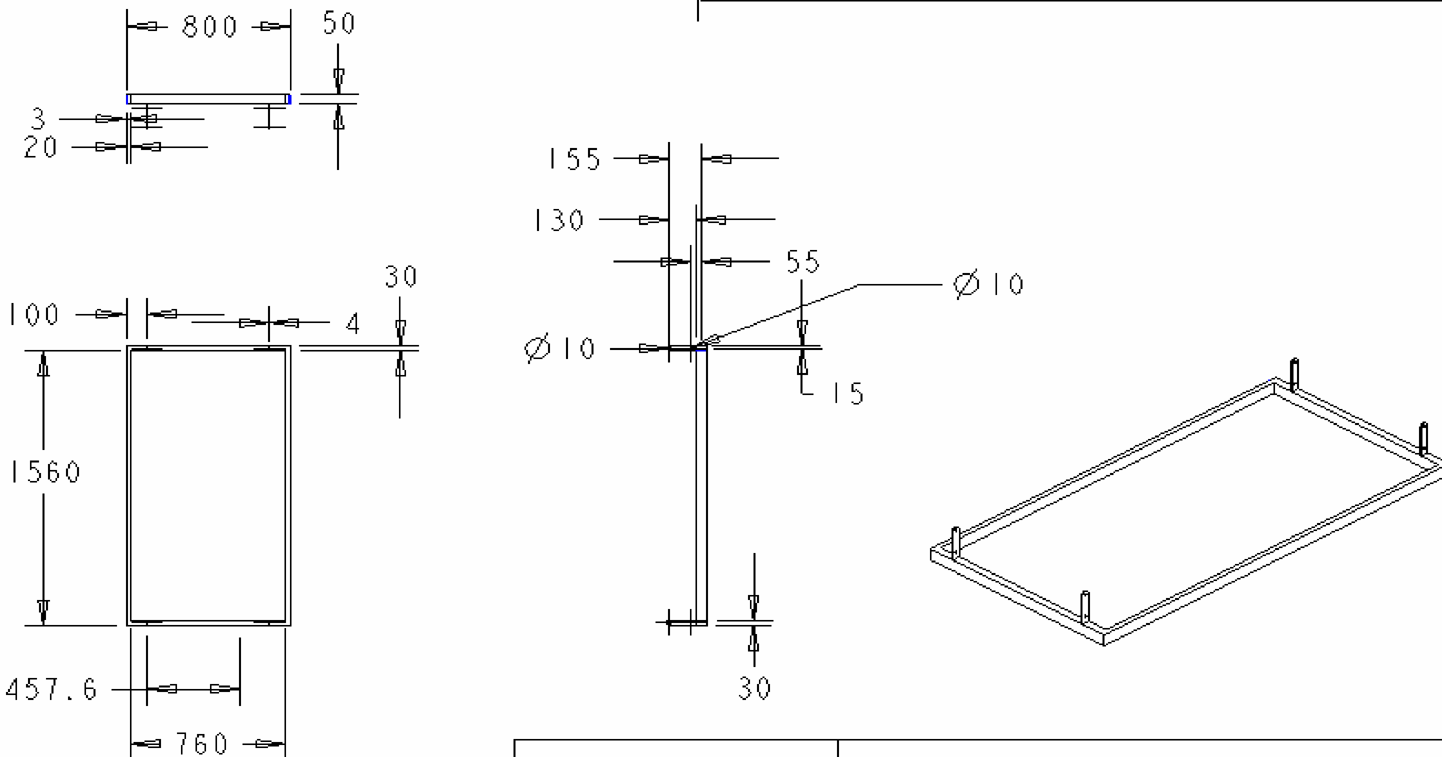
All dimensions are in mm

	WPI & HUST
	Lower Wheel Attachment
SCALE 0.500	Hospital Bed



All dimensions are in mm

	WPI & HUST
	Bed Wheel Case
SCALE 0.450	Hospital Bed



WPI & HUST

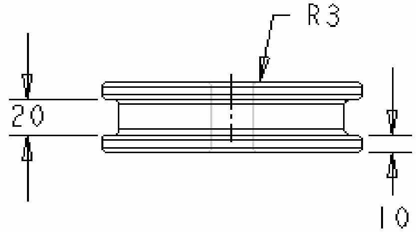
Lower Wheel Support

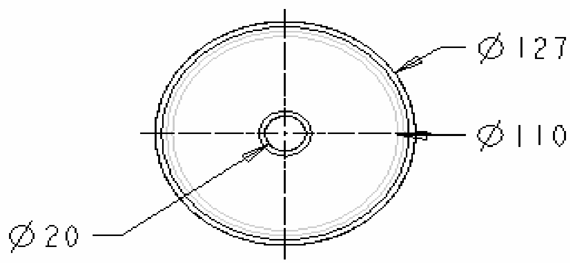
Hospital Bed

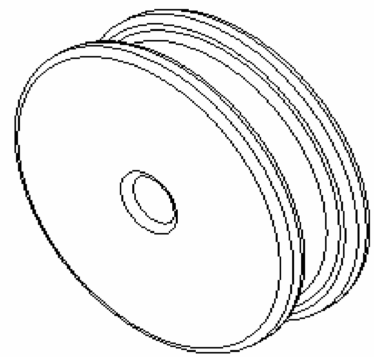
SCALE 0.033

All dimensions are in mm

All rounds are 3mm







All dimensions are in mm

WPI & HUST

Bed Wheel

Hospital Bed

SCALE 0.333

Appendix E: Lower Leg Lifting Device Mechanics Analyses

Appendix E shows the statics, stress and kinematic analyses of the lower leg lifting mechanism to reveal that the fabricated piece does in fact work.

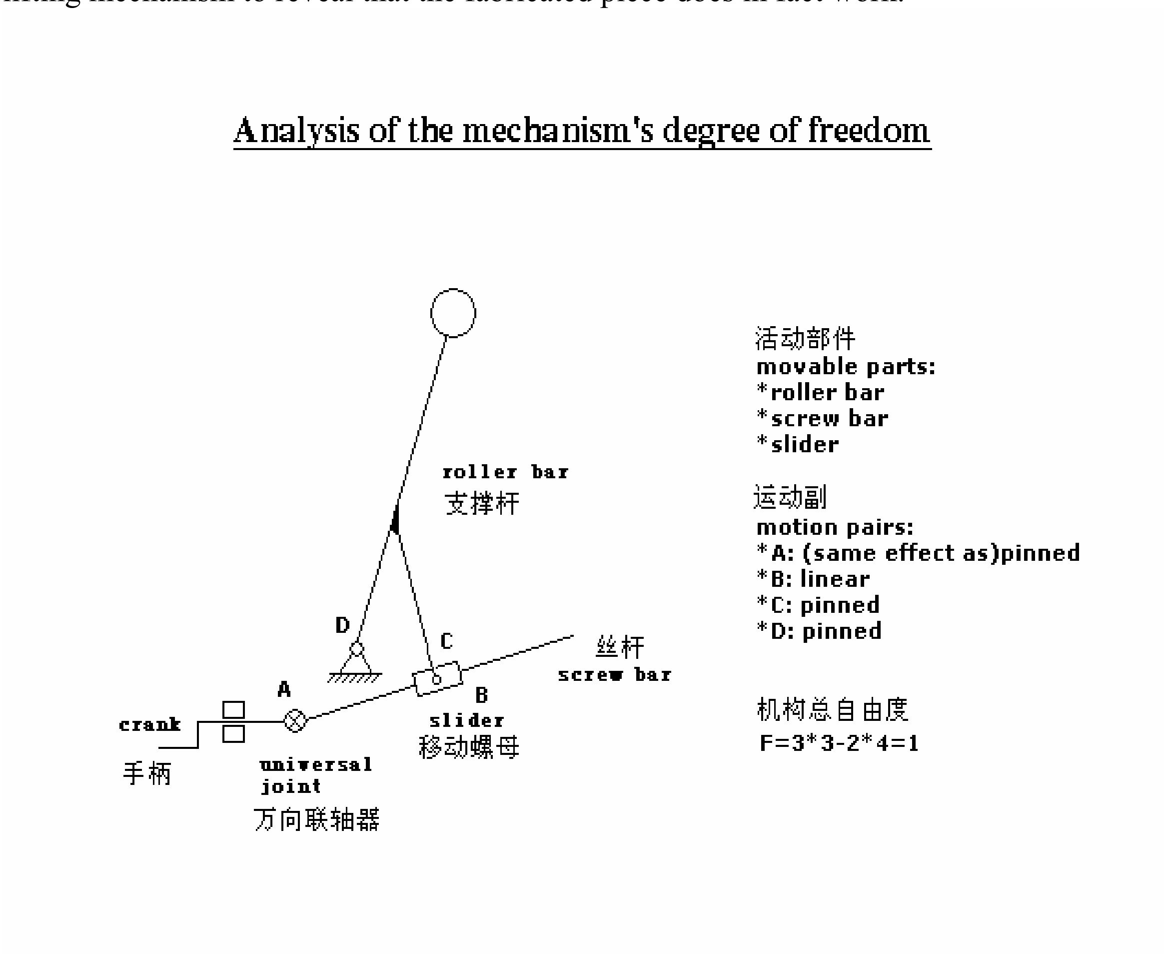


Figure 35: Evidence of a Single Degree of Freedom Lower Leg Lifting Mechanism

Given Data

$H_o := 0cm \quad \theta_{uppermax} := 60deg \quad L_{lower} := 50cm \quad L_{upper} := 35cm \quad L_{total} := 85cm$

$$H_{max} := L_{upper} \cdot \sin(\theta_{uppermax})$$

$$H_{max} = 0.303\ m$$

$$d_{translation} := L_{total} - \left[\left(\sqrt{L_{lower}^2 - H_{max}^2}\right) + L_{upper} \cdot \cos(\theta_{uppermax})\right]$$

$$d_{translation} = 0.277\ m$$

Where $d_{translation}$ is representative of the distance the extreme end of lower leg board translates when the upper leg board is inclined to its maximum of 60degrees. L lower and L upper represent the lengths of the lower and upper leg assemblies respectfully and Hmax defines the maximum height the pin between the lower and upper leg mechanisms can achieve.

Parallelogram/Jack lifting device static analysis

$$\alpha_i := 8deg$$

$$F_B := 250N$$

$$F_{O1} := \frac{F_B}{2 \cdot \cos(\alpha_i)}$$

$$F_{O1} = 126.228\ N$$

$$\alpha_f := 45 \cdot deg$$

$$F_{O2} := \frac{F_B}{2\cos(\alpha_f)}$$

$$F_{O2} = 176.777\ N$$

F_B represents the downward force of the bed, F_O represents the opposing force required to hold the parallelogram in place. Fo is divided by 2cosα due to the fact that there is an equal force acting on both side of the parallelogram.

The maximum force which may be exerted by the nurses when turning a crank as governed by the CIS is 2N*m, which is far surpassed in this instance. Equally important, the size of the links in order for this device to work would have been far too long to fit conveniently on the bed (roughly 30cm each).

Equation 1: MathCad showing the failed first iteration of the Parallelogram/Lifting Device

Sliding Jack Device Static Analysis

$L_p := 29cm$ $F_D := 250N$ $F_{AD} := \frac{F_D}{2\sin(\alpha_i)}$ $F_{AD} = 898.162\ N$

$\alpha_i = 8\ deg$ $F_{AB} := F_{AD}$ $F_{ABx} := F_{AB}\cdot\cos(\alpha_i)$ $F_{ABx} = 889.421\ N$

$F_{ABy} := F_{AB}\cdot\sin(\alpha_i)$ $F_{ABy} = 125\ N$

From the above calculations, we have determined that the force required in the y directions is 125N, thus the screw bar must be able to withstand a value of at least 12.5kg without deflection (rather nominal when considering that the material used would be some metal alloy and we thus assumed that no deflection would result). The torque necessary to turn the screw can also be found now from the x component, as defined below. We used a screw with the following components:

$D_t := 2.4cm$ Where Dt is equal to the pitch diameter

$N_t := 1$ Where Nt is the number of threads

$\rho := .3cm$ Where ρ represents the pitch

$L_t := N_t\cdot\rho$ Where Lt represents the lead of threads

$L_t = 3\times10^{-3}\ m$ on a per revolution basis

$\mu_t := .2$ An assumed coefficient of friction as .2

$$T_{SJ} := \frac{F_{ABx}\cdot D_t}{2}\cdot\left(\frac{\pi\cdot\mu_t\cdot D_t - L_t}{\pi\cdot D_t + \mu_t\cdot L_t}\right)$$

$T_{SJ} = 1.696\ N\cdot m$

Equation 2: Mathcad showing the acceptable, but still relatively high torque requirement for the sliding jack lifting device

Final Selection: Worm Gear/Roller Combo Static Analysis

Our final design was broken down into two primary components: a rolling device for the lower leg mechanism (similar to a cam-follower device) that is supported by a link which connects to the second component, a worm gear screw that rotates from the crank. As the worm gear rotates, the support link moves along the screw to raise and lower the bed.

The total length of the rolling mechanism is 32.25cm and the total length of the support bar is 12.9cm, placed at a fixed angle of 25degrees from the rolling bar and at a distance of 10cm up the rolling bar. The vertical height that the rolling device has to reach is an 30.3cm and that is satisfied when the 32.25 rolliing mechanism is at an angle of 70degrees in regard to the horizontal in the CCW direction.

$F_D = 250\ N$ $\quad \theta_{1a} := 20deg$ $\quad h_S := 32.25 \cdot cm$ $\quad \theta_2 := 25deg$ $\quad \theta_{3a} := 5deg$

$\theta_{1b} := 90deg$ $\quad \theta_{3b} := -70deg$

$\theta_{1a} + \theta_{3a} = 25deg$

$h_D := h_S \cdot \sin(\theta_{1a})$ $\quad h_x := 10.23cm$ $\quad$ hx and hy are values that were found using ProE software

$h_D = 0.11\ m$ $\quad h_y := 8.8cm$

$F_{1ya} := -250N$ $\quad F_{2ya} := 501N$ $\quad F_{1xa} := 21N$ $\quad F_{2xa} := -21N$ $\quad F_{sa} := 252N$

Given

$F_{1ya} + F_{2ya} - F_D = 0$ $\quad F_{1xa} + F_{2xa} = 0$ $\quad -F_{1ya} \cdot h_x + F_{1xa} \cdot h_y - F_D \cdot h_D = 0$

$F_{1xa} - F_{sa} \cdot \sin(\theta_{3a}) = 0$ $\quad F_{1ya} + F_{sa} \cdot \cos(\theta_{3a}) = 0$

$$\mathrm{Find}(F_{1ya}, F_{2ya}, F_{1xa}, F_{2xa}, F_{sa}) = \begin{pmatrix} -250.687 \\ 500.687 \\ 21.932 \\ -21.932 \\ 251.645 \end{pmatrix} N$$

$F_{1yb} := -250N$ $\quad F_{2yb} := 501N$ $\quad F_{1xb} := 21N$ $\quad F_{2xb} := -21N$

Given

$F_{1yb} + F_{2yb} - F_D = 0$ $\quad F_{1xb} + F_{2xb} = 0$ $\quad -F_{1yb} \cdot h_x + F_{1xb} \cdot h_y - F_D \cdot h_D = 0$

$F_{sb} := 252N$

$F_{1xb} - F_{sb} \cdot \sin(\theta_{3b}) = 0$ $\quad F_{1yb} + F_{sb} \cdot \cos(\theta_{3b}) = 0$

$$\mathrm{Find}(F_{1yb}, F_{2yb}, F_{1xb}, F_{2xb}, F_{sb}) = \begin{pmatrix} 197.704 \\ 52.296 \\ 543.188 \\ -543.188 \\ -578.048 \end{pmatrix} N$$

Equation 3 Static Analyses showing final forces, Fs, placed on the critical area of the lower leg lifting mechanism in its extreme positions

Appendix F: Security of the Screw and Nut

Appendix F uses program MathCAD to show that the screw pair is in fact a self sustaining pair which means it can reliably support the lower legs at different angles.

$$d := 24mm$$

$$p := 3mm$$

$$d_m := d - \frac{p}{2}$$

$$n_s := 1$$

$$L_m := p \cdot n_s \qquad \mu_t := 0.2$$

$$F_s := 251.645N$$

$$F_{sx} := F_s \cdot \cos(5deg)$$

$$T_r := \frac{F_s \cdot (d_m) \cdot \frac{\pi \cdot \mu_t \cdot d_m + L_m \cdot \beta}{\pi d_m \cdot \beta - \mu_t \cdot L_m}}{2}$$

$$T_1 := \frac{F_s \cdot (d_m) \cdot \frac{\pi \cdot \mu_t \cdot d_m - L_m \cdot \beta}{\pi d_m \cdot \beta + \mu_t \cdot L_m}}{2}$$

$$T_r = 0.692\ N \cdot m$$

$$T_1 = 0.442\ N \cdot m$$

$$\Psi := \operatorname{atan}\left(\frac{n_s \cdot p}{\pi \cdot d_m}\right)$$

$$\Psi = 0.042$$

$$\rho := \operatorname{atan}(\mu_t)$$

$$\rho = 0.197$$

ρ is larger than Ψ, showing that the screw pair can lock itself (Page 108 of Prof. Weiguo Zhang's book I)

Equation 4: Mathcad revealing that the screw pair is self-locking when cranked so no slippage will occur

$$h := \frac{p}{2}$$

$$\phi := 1.8$$

ϕ shoud be in [1.2,2.5] Page 82, Prof. Weiguo Zhang's book II

$$H_s := \phi \cdot d_m$$

$$p_s := \frac{F_s \cdot p}{\pi \cdot d_m \cdot h \cdot H_s}$$

$$p_s = 0.176\,\text{MPa}$$

assume the matiarial of the screw is steel(Q235 or ASTM- A36)
slider:copper(H62 Yellow-Brass Annealed). According to page 82 of Prof.Weiguo Zhang's book, 18 <=[p] <= 25 (MPa) ,p_s is much smaller than [p]. So there's no friction problem.

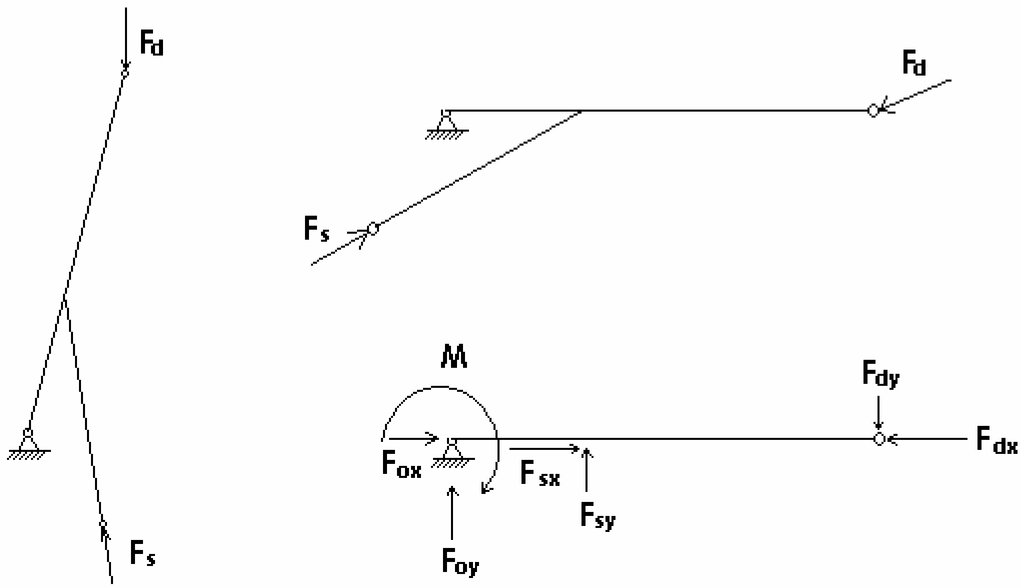
$$\tau := \frac{F_{sx}}{n_s \pi \cdot d \cdot \frac{p}{2}}$$

$$\tau = 2.217\,\text{MPa}$$

According to Page 83, 30<[τ]<40 (MPa), so
τ<<[τ]

Equation 5: Mathcad showing the friction factor of the screw and the shear stress felt

Appendix G: Stress Analyses



$F_d := 250 \quad F_s := 251.645 \quad \alpha := 20\text{deg} \quad \beta := 25\text{deg} \quad Len1 := 0.322 \quad Len2 := 0.100$

$F_{dx} := F_d \cdot \cos(\alpha) \quad F_{dy} := F_d \cdot \sin(\alpha) \quad F_{sx} := F_s \cdot \cos(\beta) \quad F_{sy} := F_s \cdot \sin(\beta)$

Assume $\quad F_{ox} := 6.855 \quad F_{oy} := -20.845 \quad M := -23.817$

Given

$$(F_{ox} + F_{sx} - F_{dx}) = 0$$

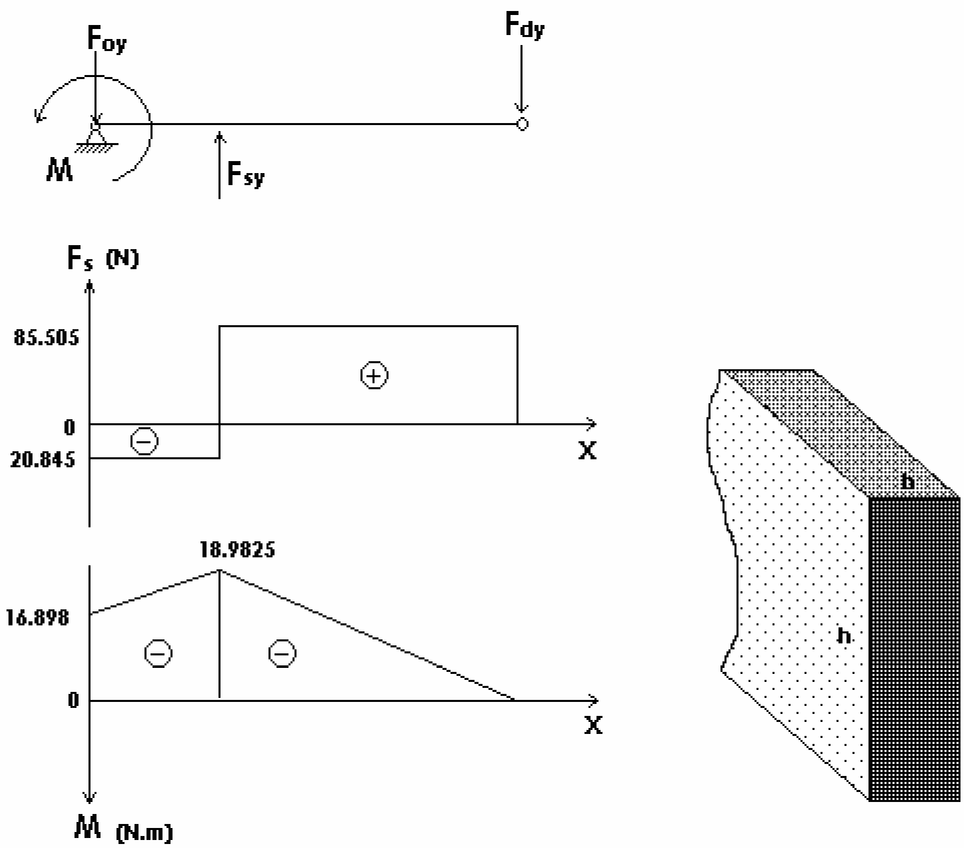
$$(F_{oy} + F_{sy} - F_{dy}) = 0$$

$$-F_{dy} \cdot Len1 + F_{sy} \cdot Len2 - M = 0$$

$$\text{Find}(F_{ox}, F_{oy}, M) = \begin{pmatrix} 6.855 \\ -20.845 \\ -16.898 \end{pmatrix}$$

$F_{sy} = 106.35 \quad F_{dy} = 85.505$

Equation 6: Calculation of Pin Forces at the Roller



$M_{max} := -18.9825 N \cdot m$

$b := 7.6mm \qquad h := 17.5mm$

$W_z := b \cdot \frac{h^2}{6}$

$W_z = 3.879 \times 10^{-7} m^3$

$\sigma_{max} := \frac{|M_{max}|}{W_z} \qquad \sigma_{max} = 48.934 MPa$

$[\sigma]$=235Mpa,σ.max<<$[\sigma]$

Equation 7: Force and Stress Diagrams and Analyses of Rollerbar

Calculation of the Radius of Curvature of the Rollerbar

$I := \frac{1}{12} \cdot b \cdot h^3$ $\quad I = 3.394 \times 10^{-9}\ m^4$ $\quad E := 200GPa$

$$\rho := \frac{1}{\frac{|M_{max}|}{E \cdot I}}$$

Where ρ is equal to the radius of curvature of the long rod supporting the lower leg platform.

$\rho = 35.762\ m$

$\frac{1}{\rho} = 0.028\ \frac{1}{m}$

As calculated from Beer, etc. in Chapter 4, pages 216-218

Calculation of the Maximum Deflection of the Rollerbar

$F_{dy} = 85.505$ $\quad F_{sy} = 106.35$ $\quad L_1 := .1m$ $\quad L_2 := .222m$

$F_{1dy} := 85.05N$ $\quad F_{1sy} := 106.35N$ $\quad P := F_{1dy}$ $\quad a := L_2$ $\quad M = -P \cdot \frac{a}{L_1} \cdot x$

Use equation 9.4 from Beer's book to find the DiffEq for the elastic curve:

$$E \cdot I \cdot \frac{d^2y}{dx^2} = -P \cdot \frac{a}{L_1} \cdot x$$

Integrate twice since EI is constant in this case. We find:

$$E \cdot I \cdot \frac{dy}{dx} = \frac{-1}{2} \cdot P \cdot \frac{a}{L_1} \cdot x^2 + C_1$$

$$E \cdot I \cdot y = \frac{-1}{6} P \cdot \frac{a}{L_1} \cdot x^3 + C_1 \cdot x + C_2$$

Boundary conditions reveal [x=0, y=0] and [x=L, y=0]. From the second integration, we find that C.2 is equal to 0. We then write:

$$E \cdot I(0) = \frac{-1}{6} \cdot P \cdot \frac{a}{L} \cdot L_1^3 + C_1 \cdot L_1$$

Which reveals that C.1=(1/6)P*a*L1

Substitute the values of C1 and C2 back into the first to equations to get:

$$E \cdot I \cdot \frac{dy}{dx} = \frac{-1}{2} \cdot P \cdot \frac{a}{L_1} \cdot x^2 + \frac{1}{6} \cdot P \cdot a \cdot L_1$$

turns to===>

$$\frac{dy}{dx} = \frac{P \cdot a \cdot L_1}{6 \cdot E \cdot I} \cdot \left[1 - 3\left(\frac{x}{L_1}\right)^2\right]$$

$$E \cdot I \cdot y = \frac{-1}{6} \cdot P \cdot \frac{a}{L_1} \cdot x^3 + \frac{1}{6} P \cdot a \cdot L_1 \cdot x$$

turns to===>

$$y = \frac{P \cdot a \cdot L_1^2}{6 \cdot E \cdot I} \cdot \left[\frac{x}{L_1} - \left(\frac{x}{L_1}\right)^3\right]$$

These derivations form the equations of the elastic curve, so that the maximum deflection can be determined and the equation of the maximum equation and consequently the degree of the maximum deflection can be found as follows:

$$0 = \frac{P \cdot a \cdot L_1}{6 \cdot E \cdot I} \cdot \left[1 - 3\left(\frac{x_m}{L_1}\right)^2\right]$$

which, when xm is solved for, reveals: $x_m = \frac{L}{\sqrt{3}}$

Substituting this value into the equation solving for y gives:

$$y_{max} = \frac{P \cdot a \cdot L^2}{6 \cdot E \cdot I} \cdot \left[\frac{x_m}{L} - \left(\frac{x_m}{L}\right)^3\right]$$

converting to:

$$y_{max} := \frac{.0642 \cdot P \cdot a \cdot L_1^2}{E \cdot I}$$

$$y_{max} = 1.786 \times 10^{-5}\ m$$

Equation 8: Radius of Curvature and Deflection of Rollerbar

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