A Robot for Hand Rehabilitation

by

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B.S. Mechanical Engineering
Massachusetts Institute of Technology, 1999

Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degree of

Master of Science

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

February 2001

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Abstract

This thesis describes the design of a robot for hand rehabilitation and is based on earlier work done in the MIT Newman Lab for Biomechanics and Human Rehabilitation. The goal of the new robot described here is to provide rehabilitative therapy to the hand.

MIT MANUS is an active therapy device previously designed and built in the Newman Lab. It has been used with success to improve strength and control of the upper extremity and promote recovery in stroke patients. However, research showed that only joints directly involved in robot therapy demonstrated greater improvement than the control group. This data was an impetus to design robotic therapy for other parts of the body.

Another factor in the development of this robot was that there is a need for functional therapy. A robot which can provide active therapy using the functional tasks of the hand would be very novel. The robot design described in this thesis fulfills the requirements of such an idea. The robot will later be combined with controls software and video games to allow for active therapy of the hand.

Included in this thesis is the background information on rehabilitative hand therapy, as well as on the anatomy and function of the hand, used for the design. Design options and choices are discussed. Finally the overall design and current status of the robot are presented.

Thesis Supervisor: Neville Hogan
Title: Professor

Acknowledgments

First off I would like to thank everyone in the Newman Lab for their help and support. In particular I owe thanks to Prof. Neville Hogan and Dr. Hermano Igo Krebs for advice and supervision. A big thank you goes to Lori Humphrey for helping out with my day-to-day questions. Particular thanks also to Rainuka Gupta and Dustin Williams for being an ear and a sanity check for the design. Thanks also to Jerry Palazzolo for help with my data acquisition questions.

Thanks also goes to the numerous people who have helped me outside of lab. Special thanks to Fred Cote and the Edgerton Student Shop. Thanks also to Matt Page for help with the ZCorp machine. Appreciation to Edmund Golaski for bearing and machine design questions and to Byron Stanley for help with the cable drive system. A huge thanks to Ebbe Bamberg for his valuable advice during the design review of the robot and for his help trying to convert Pro/Engineer files for machining. Finally, thanks to my family and friends for tons of support and many gallons of therapeutic ice cream.

The material in the thesis is based upon work supported under a National Science Foundation Graduate Fellowship.

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Chapter 1

Introduction

1.1 Purpose

This thesis describes the design of a robot for hand rehabilitation done in the MIT Newman Lab for Biomechanics and Human Rehabilitation. The goal of the robot is to provide rehabilitative therapy to the hand of stroke and other patients.

After stroke, "hand function seems to be the most difficult motor function to restore even with intensive therapy" [43]. It is also arguably one of the most important motor functions used during everyday life. For these reasons, developing a robot to help stroke patients recover hand function is both a difficult and a valuable task. The robot was designed as my Master's thesis during the year of 2000.

1.2 Outline of Chapters

In order to understand the robot design, some background is needed. Therefore, Chapter 2 describes stroke and the stages of recovery after a stroke, while Chapter 3 is a summary of hand anatomy and function relevant to the design. Chapter 4 describes the functional requirements for the robot design. Chapter 5 describes the design choices and decisions in detail, while Chapter 6 discusses the prototypes which were produced. Finally, Chapter 7 tells where the robot is today and where it is going. Drawings and calculations are included in the appendices.

Chapter 2

Background

2.1 Stroke

Stroke is a general term which refers to any acute brain disorder that is caused by a disturbance of the vascular system in the brain. There are many types and causes of stroke, though cerebral infarction due to blockage of a blood vessel in the brain is the most common [24]. Strokes, or cerebrovascular accidents (CVAS), are the third leading cause of death in the U.S. and are the most common cause of chronic neurologic disability [43]. At any one time, there are approximately two million stroke survivors in the United States alone [43].

The most common results of a stroke is weakness (hemiparesis) or paralysis (hemiplegia) on the side of the body opposite the CVA [43]. These can cause abnormal patterns of posture and movement. If left untreated, many patients recover little or no functionality in paralyzed limbs. This non-functionality can propagate chronic motor problems as the patients modify their normal side actions to compensate for the loss [14].

Physical therapy and neuro-rehabilitation treatment can reduce or eliminate these patterns and can allow patients to regain movement and control. Various studies suggest that motor recovery and re-learning to use the affected limb can be maximized by active repetitive use of that limb [15].

2.1.1 Terminology

Terms describing the muscles of a stroke victim:

Flaccidity Lack of normal muscle tone. The limb feels limp and will fall into place if not supported.

Spasticity Excess tone and hyperactive response to stretch. In moderate to severe spasticity, the limb feels tight and is difficult to move into position.

Tone Resistance of muscle to passive elongation or stretching.

Contracture Tightening of the muscles.

Synergy Patterned movements of the entire limb in response to a stimulus or voluntary effort. The patient has difficulty separating out individual muscle movements.

Terms describing the planes of the hand:

Dorsal Plane The plane through the back of the hand.

Palmar Plane The plane through the palm of the hand.

Terms describing the motion of the fingers:

Flexion In the fingers, bending towards the palmar side of the hand. In the thumb, bending across the palm towards the base of the little finger.

Extension In the fingers, bending away from the palm, towards the dorsal side of the hand. In the thumb, bending away from the palm as in a hitch-hiker's thumb.

Abduction Motion away from the center line of the hand, in a direction perpendicular to the palm.

Adduction Motion towards the center line of the hand, in a direction perpendicular to the palm.

Pronation From neutral position, rotation inwards (i.e. clockwise for the left hand and counter clockwise for the right hand).

Supination From neutral position, rotation outwards (i.e. counter clockwise for the left hand and clockwise for the right hand).

2.1.2 Stages of Recovery

In general, recovery from paralysis progresses from "proximal to distal movement and from mass, patterned, undifferentiated movement to fine, isolated movement" [43]. In the case of the arm, gross trunk and shoulder movements will occur first. Movement will continue down the arm, progressing to the elbow, wrist and finally to the fingers. Mass flexion and extension of the hand is followed by flexion and extension of individual fingers and then by abduction and adduction of the thumb [10]. More specifically, the observable stages of recovery of the hand are flaccidity, followed by little or no active movement, then mass grasping (all the fingers grasping at once), lateral prehension (holding between the side of the index finger and thumb), palmar prehension (holding between the thumb and the first two fingers) and then, finally, individual finger movements [8].

The following scale describes hand function as tested shortly after a stroke [17]:

1. No active motion in digits.
2. Active flexion of all fingers in synergy only.
3. Active flexion and extension of all fingers in synergy.
4. Ability to extend index finger with all others in flexion.
5. Ability to bring thumb in opposition to the tip of the index finger.
6. Ability to oppose thumb to all fingers.

It can generally be assumed that a patient will not be undergoing hand therapy until they have recovered at least some functionality in the muscles of their upper arm and wrist. This is not always true, however, as there are cases where stroke victims will show no movement in the upper arm but will have full control and dexterity of their fingers [19]. The robot therefore needs to be able to support itself and the wrist of the patient in case they are not able to do it themselves. Ideally the robot would also allow for passive movement of the wrist (motion initiated by the patient) for practicing functional tasks [10].

2.1.3 Edema

Edema, or accumulation of fluid in the tissue, is seen in approximately 16% of hemiplegic patients [8]. During the clinical trial work previously done in the Newman Lab, almost all patients have had significant hand edema [29]. In many cases, edema occurs due to loss of muscle action and reduced circulation [43]. Often, in the case of arm paralysis, the fingers and wrists of the patient will be extremely swollen, reducing the range of passive joint motion. This condition needs to be considered in the design of the robot; many patients with edema will fall outside of the normal anthropometric ranges for hand and finger size and will not be able to reach the ranges of motion of a normal person.

2.1.4 Grasp Reflex

Along with paralysis, a stroke victim may also demonstrate other motor disturbances. One of these can be the reappearance of the "grasp reflex", such as is seen in young infants. It is usually seen when pressure moves over certain areas of the palmar region of the hand [37, 31]. Grasping is seen in about 8% of brain damaged patients, predominantly in those with hemispheric lesions . It is also generally associated with frontal lobe pathology . For this reason, as well as for increasing functional ability, the robot design avoids contact with the palm.

Separate, but similar to, the grasp reflex is the instinctive grasping reaction. In this case, the response is elicited with a stationary pressure. The patient is compelled to close his or her hand over whatever object is touching it [37]. This reaction is also seen in patients suffering from stroke.

2.2 Synergy

Another motor impairment that a stroke patient often demonstrates is abnormal synergy. As described above, synergy is a patterned movement that the patient has trouble breaking down into individual muscle movements. The most prevalent synergies in the upper extremity are the flexion and extension synergies. These occur when the patient tries to accomplish a general flexion or extension movement.

The most common flexion synergy consists of having the arm in abduction, extension and external rotation of the shoulder, elbow flexion, forearm supination and flexion of the wrist and fingers. Extension synergy, on the other hand, consists of forward flexion, adduction and internal rotation of the shoulder, extension of the elbow, pronation of the forearm and finger and thumb extension [35]. These synergies affect the robot design in that the patient's fingers are difficult to move individually and may be affected by how else the patient is moving his or her arm.

2.3 Rehabilitation

There are several schools of thought on what type of rehabilitative therapy is most beneficial to a person suffering from hemiplegia. The most common types of therapy associated with hand rehabilitation are discussed below.

2.3.1 Continuous Passive Motion

Continuous Passive Motion (CPM) uses a therapist or machine to move a patient's limb for hours at a time. There is evidence that this method of therapy reduces edema [8, 1, 21] and is beneficial in the treatment of spastic flexion [5]. However, it requires eight hours of therapy a day to be beneficial [1], and the effect of reducing edema may only last 24

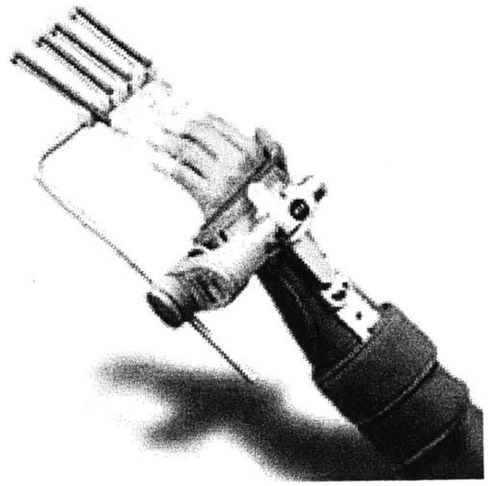


Figure 2-1: H3 Hand by Orthologic

hours [21]. CPM can help a patient with movement control, but has no effect on force control [5]. Also, since the patient is simply being moved, there is no connection between what the patient wants to do and what he or she actually does. Therefore it is helpful but cannot replace active motion of the limbs [1].

Several products on the market today are available to provide CPM for the hand. There are both portable and non-portable devices, though all of them achieve basic flexion and extension without focusing on the individual joints [1].

Portable Devices

Orthologic has two portable CPM devices for the hand. The first, the WaveFlex hand, provides composite flexion to the individual fingers. H3 hand, their second device, uses adjustable rods attached to the fingertips to provide composite flexion of all fingers at once (see Figure 2-1) [33].

The Kinetec 8091 by Smith and Nephew has finger pieces which slide onto an anatomically shaped drive bar and provide motion into a full composite fist [41]. These portable devices concentrate on the fingers and only apply composite flexion. There is no individual joint angle control and little or no interaction with the thumb.

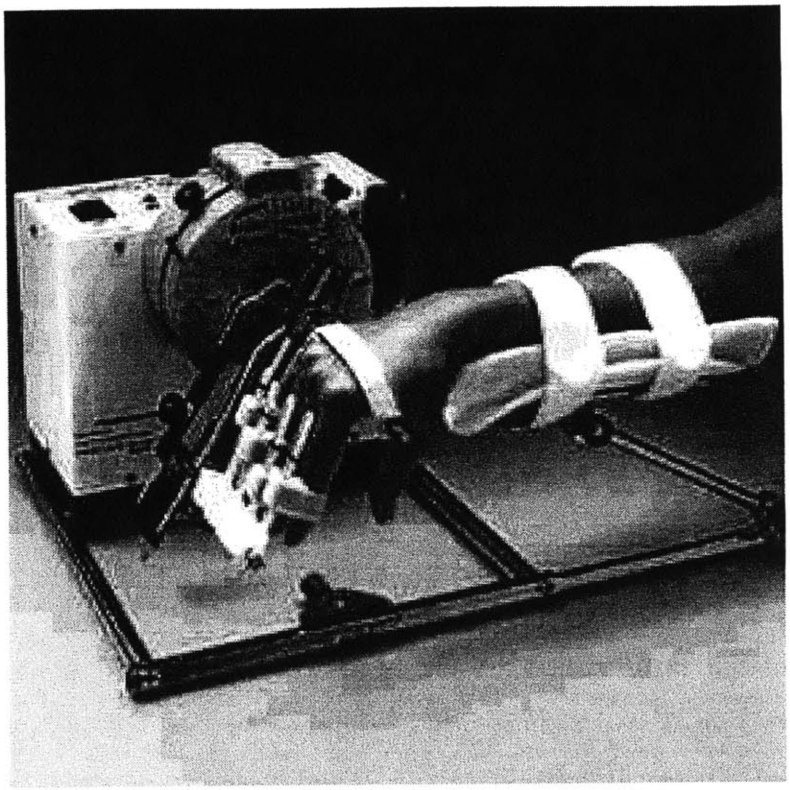


Figure 2-2: Kinetec 8080 by Smith and Nephew

Non-Portable Devices

Some of the non-portable devices do have the ability to move the thumb. For example, the Kinetic 8080 by Smith and Nephew provides composite flexion and extension of the fingers, as well as thumb flexion and extension (see Figure 2-2). However, the device does not have the ability to actuate individual joints.

2.3.2 Functional Electrical Stimulation

Another method of physical rehabilitation is Functional Electrical Stimulation (FES). FES is a technique that applies electrical pulses the peripheral nerve fiber members of disabled limb, causing the muscles to contract [43]. Studies have suggested that electrical stimulation reduces spasticity and enhances the muscle strength of the affected limb [15].

Less a type of therapy and more a way of achieving functionality, FES has been

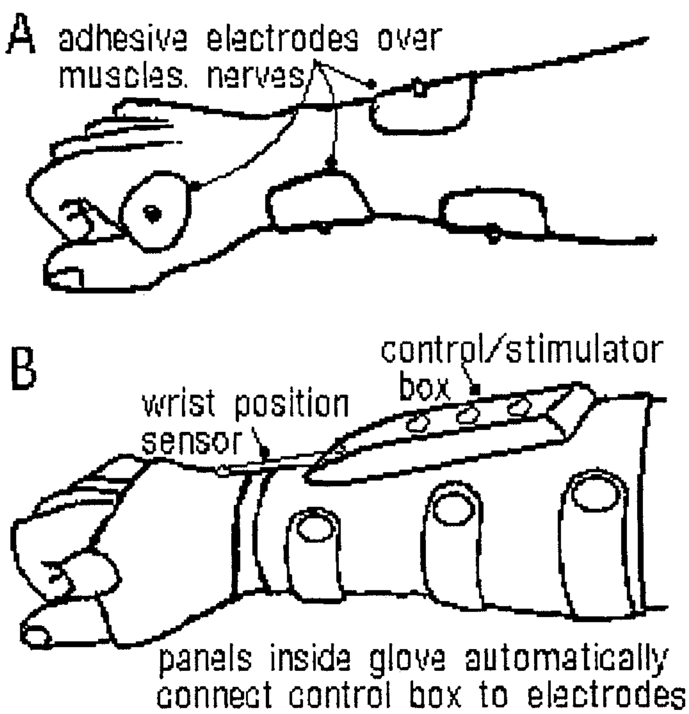


Figure 2-3: Bionic Glove

integrated into devices which the therapist or patient can use to activate otherwise inactive muscles. One such device is the Bionic Glove, designed at the University of Alberta, Canada (see Figure 2-3). In this device electrodes are placed on the skin, with the glove over them. Tightening the glove makes contact between the electrodes and metal panels in the glove itself. Stimulation is sent to these panels and into the patient via the electrodes [44].

A subset of FES is electromyography (EMG) triggered neuromuscular stimulation. The basis for this assistance is that "alternative motor pathways can be recruited and activated to assist the stroke-damaged efferent pathways." This theory is based on a sensorimotor integration theory that says that sensory input from the affected limb during movement will affect subsequent movement [14]. In other words, as a patient attempts to accomplish a movement, EMG activity in the limb is measured and when it reaches a threshold level, the limb is electrically stimulated, completing the movement. Over the span of a treatment regimen, this method is reported to help the patient gain control. However, results using the Motor Assessment Scale and Fugl-Meyer test did not show any significant improvement [14]. Also, some studies show that although the stimulation can cause function, spasticity is not reduced and voluntary action can actually reduce the effectiveness of the stimulation [27].

2.3.3 Active Motion for Neuro-Rehabilitation

A newer type of therapy, active motion therapy, has two goals. One is movement of the paralyzed limbs, to reduce edema and improve muscle strength. Along with this, active motion therapy seeks to achieve the neuro-rehabilitation necessary to control these limbs.

Brunnstrom's method states that "during the early recovery stages the hemiplegic patient should be aided and encouraged to gain control of the basic limb synergies" and for this, stimuli of proprioceptive and exteroceptive origin are justified and advantageous [37]. In layman's terms this means that giving patients external physical and visual stimuli to encourage rehabilitation can be very helpful in their recovery.

It has also been suggested that full neurological rehabilitation is possible after a stroke and that the environment in which rehabilitation occurs can play a role in this [16]. To these ends the rehabilitative robot MIT MANUS was created.

MIT MANUS

MIT MANUS combines an impedance-controlled robot with a series of video games to achieve neuro-rehabilitation. The stroke patient holds, or is attached to, the end effector of the robot while he or she attempts to play various target oriented games shown on a screen above the robot. The goals of the games vary to provide a wide range of muscle therapy. One game has the patient resist the robot as it tries to move him or her, while in another the patient tries to follow a star shaped path to several targets. In the latter game, if the patient can not accomplish the task and reach the target, the robot will help the patient do so. Figure 2-4 shows a stroke patient working with MANUS.

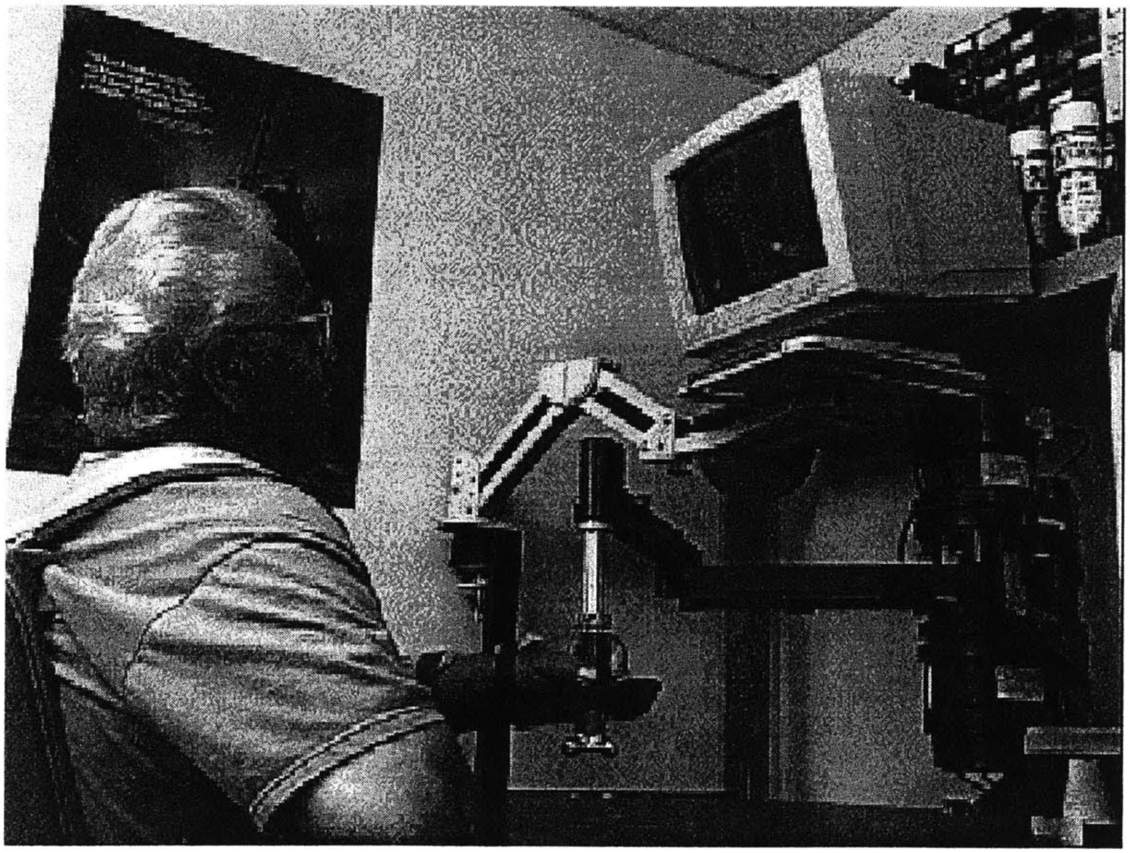


Figure 2-4: A stroke patient working with MANUS

The movements accomplished by the patient are in the plane of the robot table and use mostly the shoulder and elbow muscles. Clinical results show that patients undergoing this type of therapy "improved further and faster, outranking the control group in all the clinical assessments of the motor impairment involving shoulder and elbow" [26].

An additional degree of freedom in the vertical direction was designed for MANUS in the Spring of 2000. The movements aided by this new design should increase the usefulness of MANUS for the re-learning of functional tasks. The robot can now be used to simulate lifting something from the table to the patient's mouth, placing something on a shelf and other such common tasks.

Hand Robot

The clinical research done on MANUS also showed that only joints directly involved with the robot therapy demonstrated greater improvement than the control group [26]. This data was an impetus to design robotic therapy for other parts of the body. Along with this data, there was a desire to achieve more functional rehabilitation. It is unusual for a hemiplegic patient to use the affected hand for any type of activity until finger and thumb extension can be accomplished without synergy [35]. Therefore, helping the patients reach that point is very important.

For these reasons, among others, a design for a robot to provide active motion therapy for the hand was desired. The robot design described in this thesis fulfills the requirements of such an idea. The robot will later be combined with controls software and video games to allow for active therapy of the hand.

Chapter 3

Hand Anatomy and Function

3.1 Joints

In order to understand the design of the robot, it is necessary to know a little about the anatomy and function of the hand. Of particular interest are the joints of the hand and their ranges of motion since this is what the robot must actuate. Anthropometric data, or human factors data, is useful for the sizing of the device. Finally, the functional grips used in everyday activities are of interest if the robot is going to provide such function.

3.1.1 Anatomy

The fingers contain 12 joints. Four, the metacarpophalangeal (MCP) joints, are located at the base of the fingers at the first knuckle. Another four, the proximal interphalangeal (PIP) joints, are between the first two phalanges of the fingers at the second knuckle. The distal interphalangeal (DIP) joints are the last knuckle on the fingers, between the second and third phalanges. Figure 3-1 shows the various bones and joints of the hand.

The thumb has three joints. The carpometacarpal (CMC) joint is located at the base of the thumb, near the wrist. The metacarpophalangeal (MCP or MP) joint is located at the crook between the index finger and thumb. Finally, the interphalangeal (IP) joint is between the two phalanges of the thumb at the knuckle.

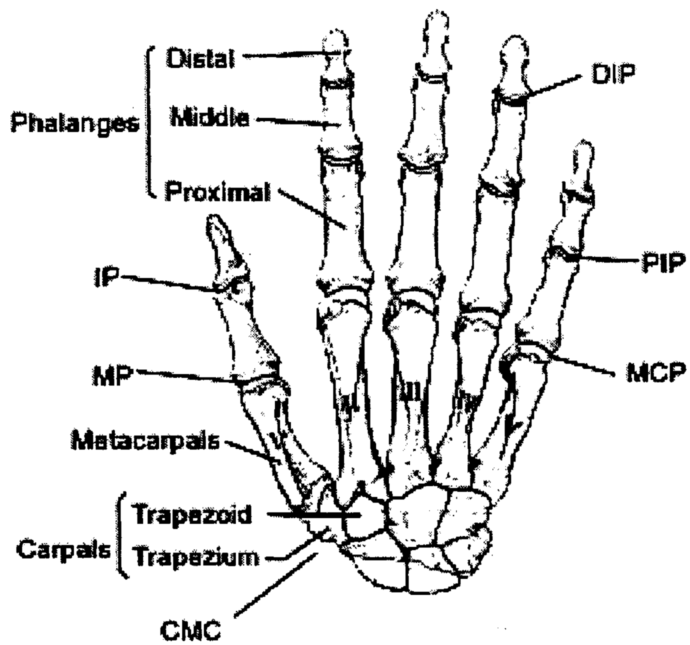


Figure 3-1: The bones and joints of the hand (Adapted from [22])

All the joints are actuated by the pulling of various tendons at attachment points along the bones of the hand. There are generally two opposing tendons for each degree of freedom of a joint. Large scale motions, such as flexion and extension of the fingers, are also accomplished by the extrinsic muscles of the hand. Fine motor control and smaller motions of the hand are accomplished by the intrinsic muscles. Generally speaking, the extrinsic muscles are much stronger and more important functionally than the intrinsic muscles.

3.1.2 Degrees of Freedom

The joints in the fingers and thumb all have either one or two actuated degrees of freedom. The first degree of freedom is flexion and extension, while abduction and adduction provide the second degree of freedom. For some joints, when these two degrees of freedom are actuated at the same time, pronation or supination occurs as well. In joints with only

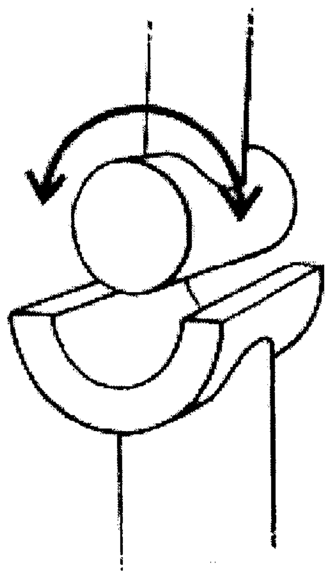


Figure 3-2: A Hinge Joint (Adapted from [25])

flexion and extension, such as the DIP joints, the PIP joints and the IP joint, the joint itself can be modeled as a pin or hinge joint [11, 13] (see Figure 3-2). In actuality, the distal phalange rotates inside a cup-like shape on the proximal phalange (see Figure 3-3).

For the DIP and PIP joints of the fingers, the axis of rotation is almost perpendicular to the finger itself. In the case of the IP joint, the axis is not perpendicular to the bone and the result is some pronation as the joint flexes to aid in opposition. As the joint flexes, the distal phalange goes through 5 to 10 degrees of pronation [6]. Figures 3-4and 3-5 show the joints and axes of rotation for the thumb.

The joints with both flexion/extension and abduction/adduction, which are the MCP joints and the CMC joint, can be modeled as a saddle or universal joint [11, 13]. In this case, the proximal bone provides a "saddle" over which the distal bone can rotate in two directions (see Figure 3-6). Both degrees of freedom can be actuated simultaneously as in a universal joint. The CMC can also be modeled as two hinge joints twisted with respect to one another [4]. Since these pivots are not perpendicular to each other, the combination of flexion/extension and abduction/adduction also creates rotation.

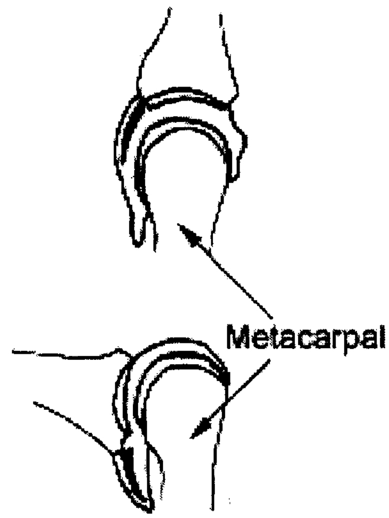


Figure 3-3: Rotation of phalanges in joints (Adapted from [32])

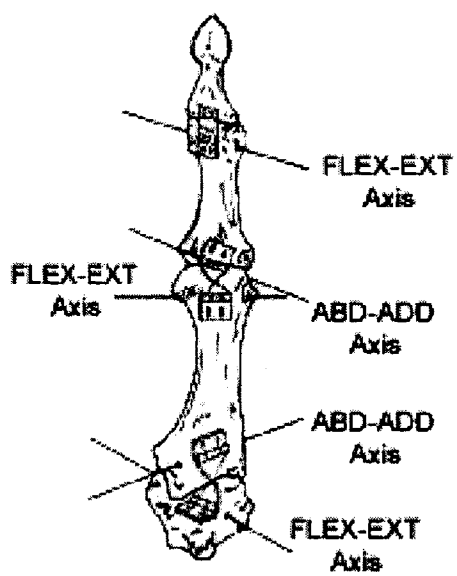


Figure 3-4: Axes of rotation for the thumb joints (Adapted from [4])

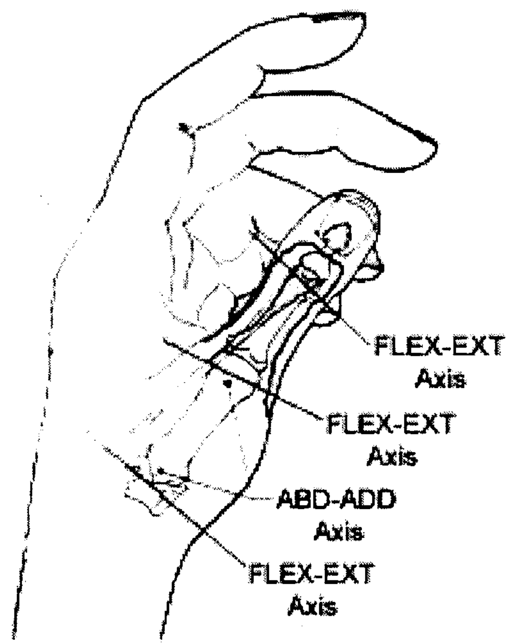


Figure 3-5: Thumb axes with respect to the anatomy (Adapted from [4])

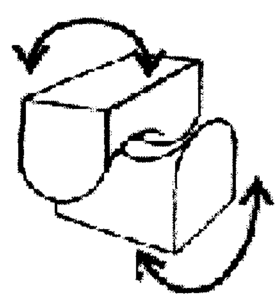


Figure 3-6: A Saddle Joint (Adapted from [25])

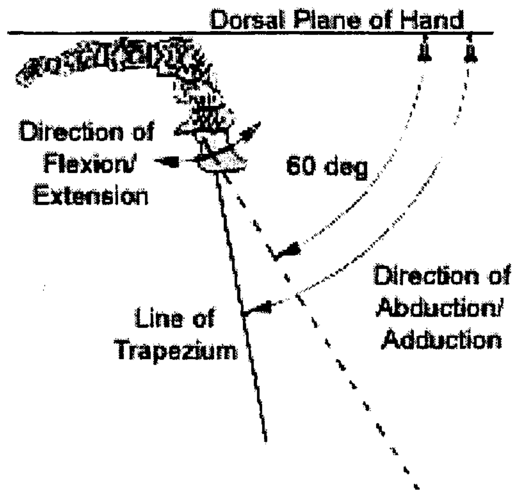


Figure 3-7: Location of thumb in neutral position (Adapted from [30])

When the CMC joint is abducted, it also rotates laterally, while when the joint is adducted, it also rotates medially [6]. This conjunct rotation is what allows the thumb to oppose the fingers. In the neutral position, the finger joints are more or less in the plane of the fingers. The thumb however is rotated about 60 degrees in the palmar direction from the dorsal plane of the hand [30] (see Figure 3-7).

3.1.3 Ranges of Motion

The two main ranges of motion (ROM) are flexion/extension and abduction/adduction. As mentioned above, all the finger joints (MCP, PIP and DIP) are able to achieve flexion and extension. Only the MCP joints have abduction and adduction however. Figure 3-8 shows the movements of the MCP.

In the case of the MCP joints, abduction and adduction are the responsibility of the intrinsic muscles of the hand. Also, as the MCP joint flexes or extends, abduction and adduction become much more difficult due to the geometry of the joints. Abduction and adduction take the longest to come back to a patient after a stroke [10]. In addition, these movements are not necessary for a majority of functional tasks. For these reasons, the robot does not have actuation in these degrees of freedom.

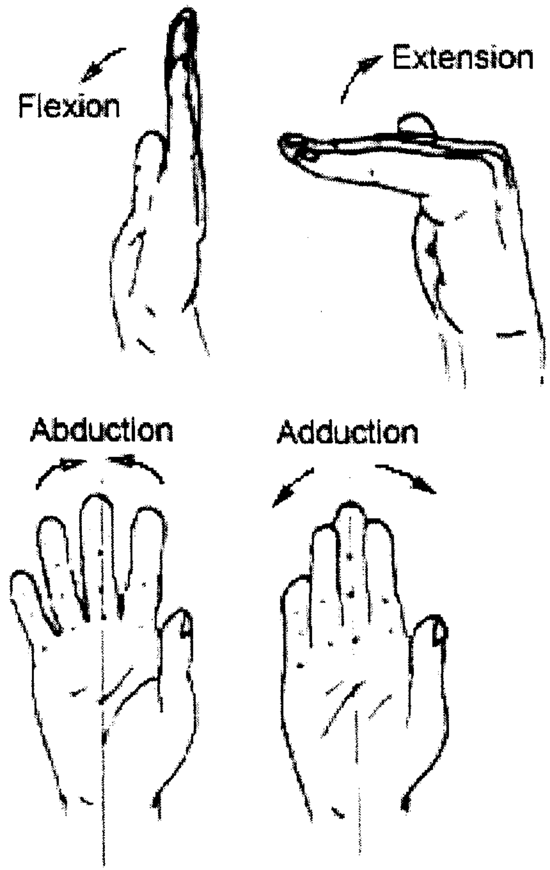


Figure 3-8: Motions of the MCP joint (Adapted from [32])

Author	MCP	PIP	DIP	CMC	MP	IP
Chao	85.5	89.5	50.36	50.4 aa		
Becker	85.58	107.15	73.64			
Smutz	20/25	60/10	60/20	20/20 aa	15/15 aa	
Eaton	90/45	100/0	80/0	60 f	55/10	80/15
Hume	100/0	105/0	85/0	56/0	73/5	
Arbuckle	65/6	100/5	91/0			
Palastanga	90/50	90+/2	80/5	40-50, 0/80 aa	45/0	90/10
Merck	90/30	120/0	80/0	70/0, 0/25 aa	90/0	

Table 3.1: Joint Ranges of Motion

The motions of the joints of the thumb are more complex. At the CMC there is flexion/extension and abduction/adduction, as well as some rotation when opposition is achieved (see Figure 3-9). At the MP and IP joints, however, there is mostly flexion and extension. Some rotation occurs depending on the grasp but it is passive and is a function of the shape of the joint interface (see Figure 3-10).

Extensive research has been done on the ranges of motion of the human hand and there is general consensus about what those ranges are. Table 3.1 gives the results of several range of motion studies. The following abbreviations are used: f=flexion, fe=flexion/extension, ad=adduction, aa=abduction/adduction. If no designation is given, flexion/extension is implied. In the table, one value signifies the entire ROM of that joint, with no regard for the neutral position. Two values signify the range from neutral in flexion/extension or abduction/adduction, in that order. All values are in degrees.

3.1.4 Anthropometric Data

There has also been extensive work done to obtain anthropometric data on the human hand. Done mostly through military projects, this data, also known as human factors data, can be used to size the robot. Ideally, the robot should be able to fit anyone from

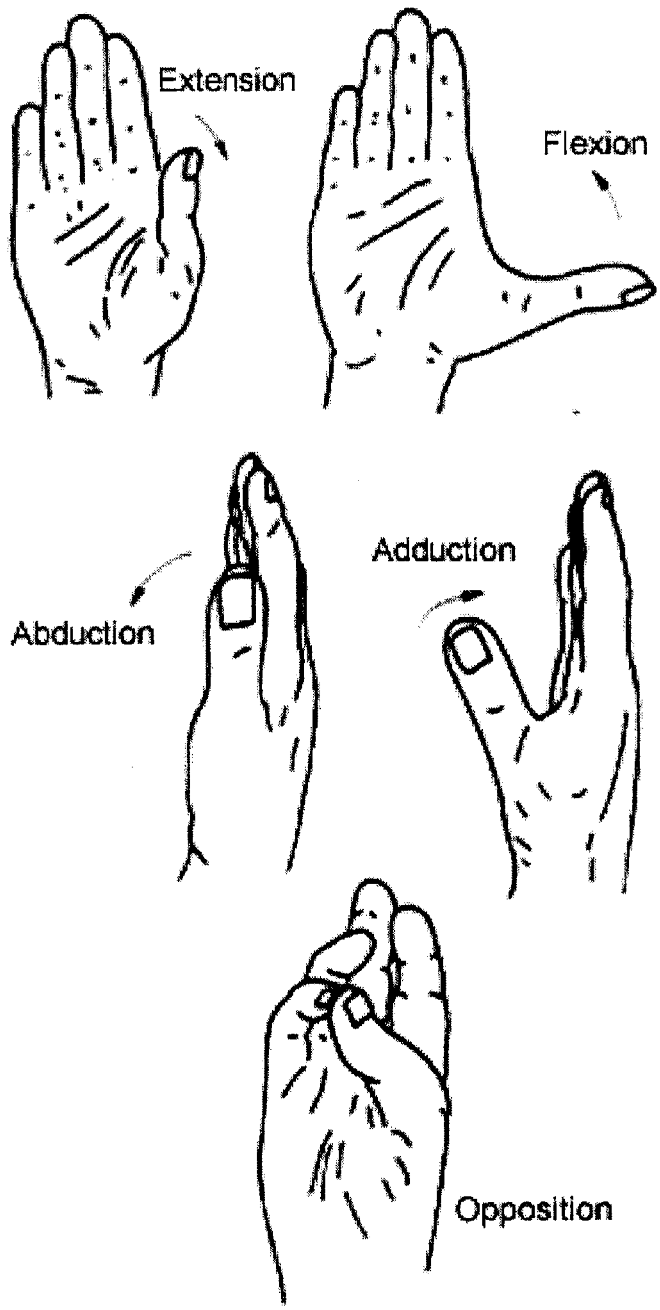


Figure 3-9: Motions of the CMC joint (Adapted from [32])

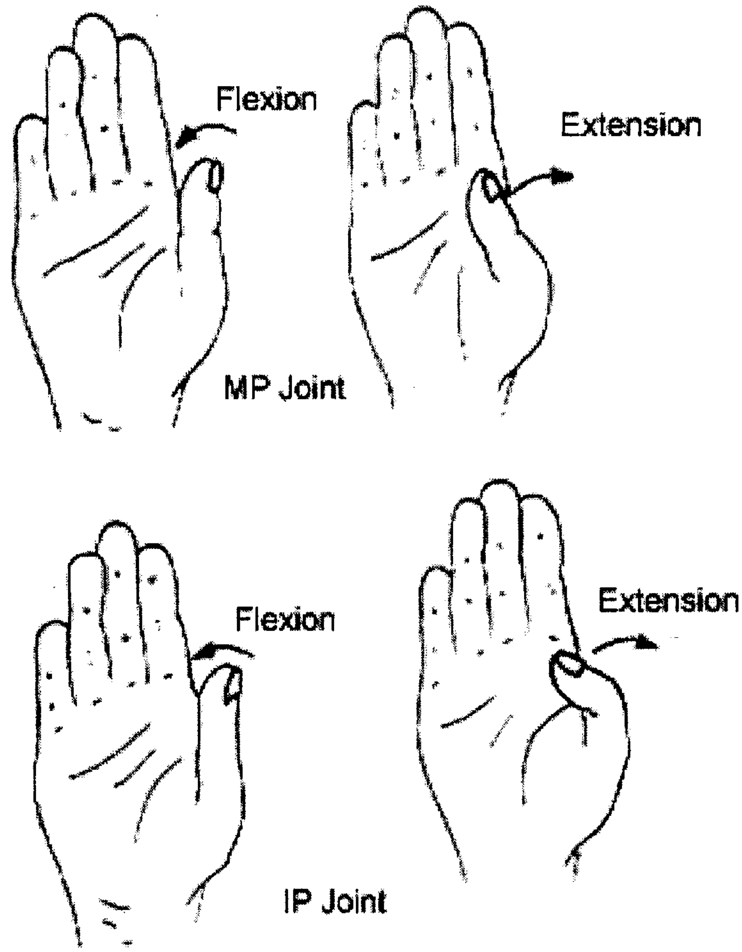


Figure 3-10: Motions of the MP and IP joints (Adapted from [32])

the 5th percentile woman to the 95th percentile man. As mentioned in Section 2.1.3, some patients may be even larger than this 95th percentile. Appendix A contains the various anthropometric measurements and their values.

The range of sizes is quite large and therefore the robot needs to either be highly adjustable or there need to be several sizes to accommodate all types of patients. Also, there are some measurements that are not well known, such as the exact location of the joints inside the fingers. For this reason, the robot design should have a some compliance built into it so as to avoid poor kinematics resulting from not co-locating the robot joint with the patient joint.

3.2 Function

3.2.1 Types of Grip

There is varied thinking on what movements are most necessary and should be relearned first. The following is a review of the most common types of grips tested and used in rehabilitation of hemiplegic patients. Ideally, the robot should be able to help the patient accomplish all of these tasks.

One established rehabilitative therapy strategy for stroke is Brunnstrom's movement therapy [37]. This therapy consists of eight tasks which follow the order of returning movement and control. The therapy tasks are:

Hook grasp This is the type of grasp used to hold the handles of a bag. It requires flexion of all the fingers at once but not to their full range of motion (Figure 3-11).

Lateral prehension This type of grip is used to pick up an item such as a card between the thumb and the side of the index finger (Figure 3-12).

Palmar prehension This type of grip is used to hold an item such as a pencil between the thumb and the first one or two fingers. Also known as pincer grasp (Figure 3-13).

Figure 3-11: An example of hook grasp [39]

Figure 3-12: An example of lateral prehension [13]

Figure 3-13: An example of palmar prehension [13]

Figure 3-14: An example of cylindrical grasp [39]

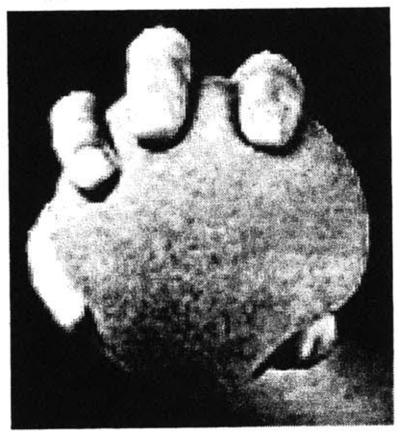


Figure 3-15: An example of spherical grasp [39]

Cylindrical grasp This grasp is used to pick up medium sized cylindrical objects, such as a small jar, in the palm using the fingers and thumb (Figure 3-14).

Spherical grasp Similarly, this grasp uses the fingers and thumb to hold a round object, like a ball, in the palm (Figure 3-15).

Opposition This grip places the thumb to the tip of the index finger (Figure 3-16).

Thumb This task is general movement of the thumb by itself up and down, as well as side to side.

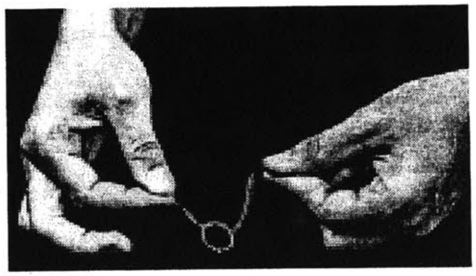


Figure 3-16: An example of precision pinch [39]

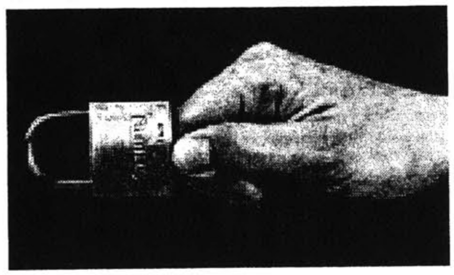


Figure 3-17: An example of key pinch [39]

Fingers This task is flexion and extension of individual fingers by themselves.

Other functional tasks which are used for rehabilitation include [13]:

Key pinch This pinch is used as its name implies, to hold a key. The thumb is pressed to the side of the index finger as the finger is in flexion (Figure 3-17).

Chuck grip This grip is similar to Brunnstrom's palmar prehension, using the thumb and first two fingers to hold a slender cylindrical item as in a drill chuck (Figure 3-18).

Power grasp This grasp is used to hold a hammer or such object. The fingers are in flexion around the object and the thumb is along the object for stabilization (Figure 3-19).

Figure 3-18: An example of chuck grip [39]

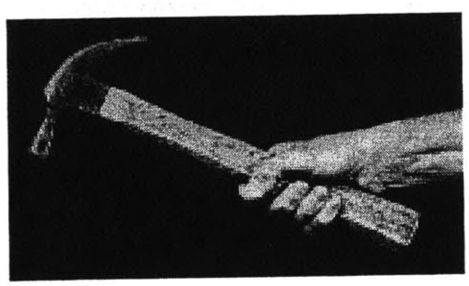


Figure 3-19: An example of power grasp [39]

3.2.2 Motor Assessment

There are several tests which are used to determine the status of a stroke patient. Of the most interest for the design of this robot are the tests of upper extremity function. In particular, prior work in the Newman Lab has focused on using the Fugl-Meyer Assessment, the Motor Status Score, and Motor Power to assess impairment. Recently the FIM and the Chedoke Arm and Hand Activity Inventory (CAHAI) are being investigated as ways to assess functional competencies [18].

The Fugl-Meyer is based heavily on the functional grasps described by Brunnstrom and consists of seven tests:

1. Fingers, mass flexion
2. Fingers, mass extension
3. PIP-DIP hook grasp
4. MCP joints extended, PIP and DIP joints flexed
5. Thumb adduction with paper, all other joints at zero
6. Pincer grasp with pencil
7. Cylinder grasp with small can
8. Spherical grasp with tennis ball

The Motor Status Score is more specific, focusing on individual motions and opposition. It includes most of the Fugl-Meyer tests as well as several tests for pad pinch and tip pinch to the various fingers.

Finally, the CAHAI is the most functional of the three tests. It consists of several everyday tasks which the patient must complete, either by him or herself or with the aid of a therapist. Representative tasks include opening a jar of coffee, calling 911, doing up buttons and putting toothpaste on a toothbrush. These tasks, although they do not focus on specific "functional" grips, are very similar to the activities that a patient may have to do on their own after they leave a rehabilitation setting. These are the tasks that are most difficult to practice with existing therapeutic devices.

3.2.3 Functional Tasks

According to occupational therapist Lisa Edelstein at Burke Rehabilitation Hospital in White Plains, NY, the most useful generic functional tasks are thumb opposition to the little finger, prehension between the thumb and index finger as well as between the thumb and first two fingers, and mass grasping [10]. As mentioned above, one of the most important functional movements is bending all of the fingers around an object. In this movement, also known as a composite fist, all of the joints of the fingers are used. The order of motion is as follows [2]:

1. The MCP flexes
2. The PIP begins to flex with the MCP, with the PIP flexing slightly more than the MCP. From about 20 to 90 degrees, the DIP also flexes with the PIP.
3. At flexion of about 100 or 110 degrees, the PIP stops movement and the MCP continues to flex
4. At the end of the movement, the PIP flexes a bit more.

With opposition of the thumb to one of the fingers, motion of the CMC and the thumb MCP are coupled together [12]. Three elementary movements make up opposition. The first is flexion and abduction simultaneously at the CMC. During this movement, the MP joint also flexes and abducts. Next there is active rotation of the metacarpal. Finally there is adduction at the CMC joint [40]. At the completion of the movement, there is about 20 degrees of abduction at the thumb MCP joint and 40 to 50 degrees of abduction at the CMC. Flexion varies on which finger the thumb is opposing and what, if anything, is being grasped, and pronation is about 70 degrees at the CMC joint [40].

Another concern for the robot design is the position of the wrist during functional tasks. If the robot is stabilizing and supporting the wrist, it must be in an orientation that allows for easy movement of the fingers. Generally the functional position of the wrist is 20 to 25 degrees extended, with 0 to 10 degrees of radial deviation [34, 10]

3.2.4 Forces

It is well established that different types of grip result in varying forces provided by different fingers. The goal was to determine what was the maximum force the robot needed to provide. A survey of prior research showed a wide variability in the published data.

The main cause of this variability is that no two researchers have done exactly the same experiment. The experiments also have mostly been done on cadavers or normal subjects. Only the work done by Mayo was on stroke patients. Therefore I assumed that the maximum force necessary would be one half to three quarters of what a normal patient would be able to exert.

Because of the variability and difficulty in understanding what a grip force of 52 N really is, hands-on experimentation was also used to get a better feeling for the maximum and normal forces exerted. Using a Chatilon device capable of measuring the force used to displace two sides of a frame, I tested my grip force. I found my maximum grip force to be approximately 60 lbf (266.9 N) and my "normal" grip force to be about 20 lbf (88.96 N). "Normal" grip force was defined by the amount of force that would be necessary to firmly hold a can of soda or other similar object.

Using a spring scale, I was also able to measure the flexion force of my index finger, the rest of my fingers and my thumb at various joints. The data collected is shown in Table 3.4. My results were within the range of the published results.

Another source of force information was previous devices. By looking at the force provided by various existing products it was possible to get a better feel for what forces were needed and appropriate to apply to a patient. The chosen provided forces will be

Strength Measure (N)					
	Chao	Kroemer	NASA	Boatright	Mayo
Tip Pinch (Men)					
Index	63.06	50			
Middle	63.35	53			
Tip Pinch (Women)					
Index	47.27				
Middle	45.7				
Palmar Pinch (Men)					
Index	64.53	63			
Middle	62.37	61			
Palmar Pinch (Women)					
Index	44.62				
Middle	44.82				
Grip Strength (Men)	367.85	318	500.78	336.73	318.72
Grip Strength (Women)	218.69		296.01	209.07	191.23

Table 3.2: Force Table 1

Strength Measure (N)			
	Chao	Radwin	Richards
Index MCP Flex/Ext	35.1	52.67	58.84
Index PIP Flex/Ext	33.75		
Index DIP Flex/Ext	34.96		
Middle MCP Flex/Ext		52	
Ring MCP FLex/Ext		34.67	
Little MCP Flex/Ext		26	
Thumb CMC Flex/Ext			32.36

Table 3.3: Force Table 2

Experiment	Max Force
Index alone	10 lbf (44.48 N)
Middle through little	10 lbf (44.48) N
Thumb CMC	15 lbf (66.72 N)
Thumb MP	10 lbf (44.48 N)
Thumb IP	10 lbf (44.48 N)

Table 3.4: Experimental Force Results

discussed later in Section 5.2.1.

Chapter 4

Functional Requirements

The first task in any design is to determine what the design needs to do. In the case of this robot, the two major classes of requirements were the kinematics and the patient interaction. Kinematics include the degrees of freedom (DOF) of the robot as well as the ranges of motion through which it will move the patient. Patient interaction requirements define how the robot will work with the patient and how the patient will interact with the robot.

4.1 Degrees of Freedom (DOF)

4.1.1 Individual Joint DOF

It was determined early on that to accomplish the robot in a timely manner, not every function of the hand would be simulated. To this end, not all the fingers are individually actuated. The middle, ring and little fingers are actuated together while the index finger and thumb are done separately. This allows for mass grasping action of all fingers and thumb, as well as more delicate grasping using only the index finger and thumb.

Also, abduction/adduction in the fingers and distal thumb joints was eliminated for a couple of reasons. For one, these movements do not have a large impact on the basic functionality of the hand; they are more instrumental in fine motor control. Also, these movements are controlled by small intrinsic muscles in the hand. These muscles are difficult to actuate and not usually controllable by the patients who would use the robot. Therefore the design only actuates flexion/extension of the finger and distal thumb joints.

In the thumb, however, abduction/adduction of the CMC joint is necessary for the vital movement of opposition. Flexion/extension is also necessary in this joint and so both degrees of freedom are actuated in this joint.

4.1.2 Number of Actuated Joints

Another simplification that was made was the number of joints actuated on the individual fingers. Although the fingers have three joints each (see Chapter 3), most functions do not require specific movement of each individual joint. In fact, it is impossible to bend the PIP and DIP joints on the finger independently. The kinematics of the patient hand will determine the exact path of the finger tips as the hand opens and closes. For these reasons only two actuated finger joints were designed into the robot. The MCP is actuated to separate it from the PIP and DIP for movements such as hook grasp and flat hand grasp. The DIP and PIP are actuated together for actions such as a composite fist. This convention reduces the clutter on the back of the hand, simplifies the power transmission and leaves more room for anthropomorphic variability.

The thumb however has all its joints actuated since it plays a vital part in almost all functional tasks. Therefore, as mentioned earlier, the CMC is actuated in flexion/extension as well as abduction/adduction, while the MP and IP joints are actuated only in flexion/extension.

The total number of DOF in the robot is eight: two for the middle, ring, little finger group, two for the index finger and four for the thumb.

Finger MCP	45° extension	90° flexion
Finger PIP	0° extension	110° flexion
Thumb CMC	20° abduction	45° adduction
Thumb CMC	20° extension	60° flexion
Thumb MP	10° extension	60° flexion
Thumb IP	20° extension	90° flexion

Table 4.1: Individual Joint ROM

4.2 Ranges of Motion (ROM)

In addition to determining which joints needed to be actuated, it was necessary to determine their ranges of motion. Most stroke patients will not have full mobility in their hands, especially at the start of therapy, but it was deemed important for the robot to be able to span the entire range. Based on clinical research and measurements (see Chapter 3), the ranges of motion shown in Table 4.1 were chosen as functional requirements.

4.3 Patient Interaction

The most important functional requirements of the robot center on how the patient and the robot interact. Many of the patients the robot will interact with are elderly and have never used a computer, let alone a robot, before. To that end, these general patient interaction requirements were made: safety, comfort, ease of use and aesthetics.

4.3.1 Safety

Since we are dealing with human subjects, keeping the robot safe is our paramount concern. This includes not applying excessive force, including software and hardware stops if necessary and avoiding shapes and mechanisms which could pinch or otherwise injure the patient. Also included in this is the ability to back-drive the robot. The patient or the therapist should be able to do this when the robot is not powered for both therapy and safety reasons.

4.3.2 Comfort

Early in the design process, it was obvious that the robot would have to have direct physical contact with the patient. This contact is in the form of a simplified exoskeletal frame which applies force to the patient's hand to move his or her fingers and thumb. It is very important that neither this force nor the connection where it is applied is uncomfortable.

Some possible methods of accomplishing this are using flexible, ergonomic connections to the patient, incorporating padding into the robot structure and limiting the pressure applied to the patient. The actual implementation of these designs is described in Chapter 5.

Adjustability is another aspect of comfort. The robot, either as a single model or several sizes, needs to accommodate almost any size patient. As mentioned in section 2.1.3, patients can have severe swelling in their hands. This needs to not affect the comfort or functionality of the robot.

4.3.3 Ease of Use

Another important requirement is the robot's ease of use. In this case ease of use refers to the therapist's ability to get the patient in and out of the robot in a short amount of time. Therapy time is very limited (about 1 hour) for our patients so it is highly undesirable to have it take 15 minutes to get a patient in and out of the robot.

4.3.4 Aesthetics

As mentioned earlier, the robot is a foreign object to many of our subjects. Some patients even named our previous robot in order to make it seem less scary and strange. It is therefore important for the robot to seem non-threatening. Especially since the robot will be surrounding and touching the patient's hand, we want them to feel comfortable with it. Some possible ways of achieving this feeling is using small, streamlined parts, using plastics and colors instead of metallics and keeping the overall machine simple.

4.4 Summary of Functional Requirements

Below is a summarized list of the robot functional requirements just discussed.

1. Must be adjustable (ideally 5th percentile woman to 95th percentile man). Must be adjustable enough to deal with edema in the patient's hand.
2. Must be easy to put on and take off the patient (less than 2 minutes each way)
3. Must be back-drivable by patient
4. Must not cause pain or injury to the patient
5. Must actuate the fingers and thumb with the DOF and ROM discussed above
6. Must be compact and aesthetically pleasing to the patient
7. Must have accurate measurement and control of the actuated joints

Chapter 5

Design

This chapter describes the design choices that were made, including the actuators, transmission, sensors and general hardware. There were several choices for almost all of the design components. These choices are discussed briefly, then the chosen component is described in detail. Also included are some of the basic design equations and criteria that were used. For complete equations see Appendix B.

5.1 General Design

The general design for the robot consists of a main cradle piece in which the patient's wrist is held. Attached to this piece are several cantilevered pieces that reach out over the hand to transmit force to the fingers or thumb. This configuration allows the robot to move the patient's digits without significant exoskeletal connections. The main advantages of this design are that the robot is not bulky or intimidating and is easier to get on and off the patient. See Figure 5-1 for a top view of the device.

The human hand is very complex kinematically; if the joint movements are not matched to a good degree by the robot, (1) the robot will not accomplish the necessary therapeutic movements and (2) the robot will hurt the patient. Neither of these are acceptable.

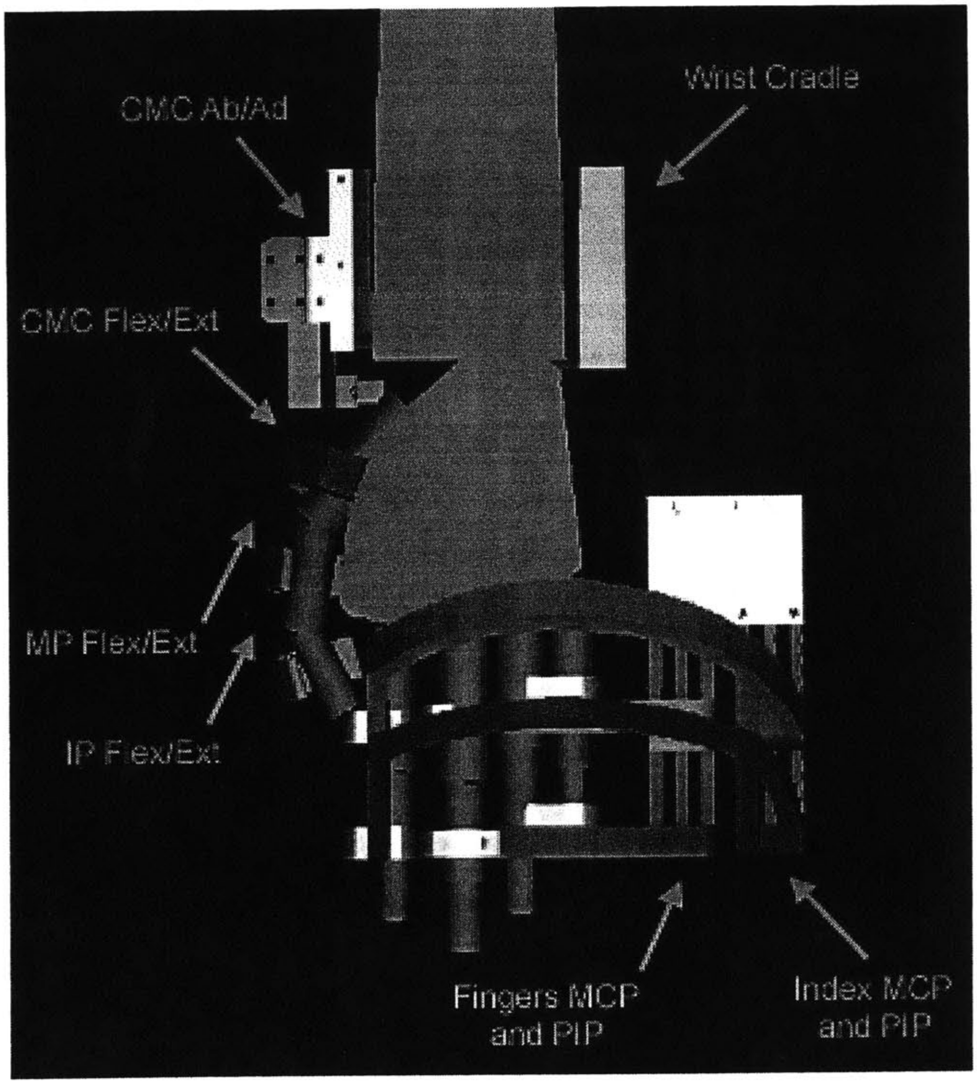


Figure 5-1: General Top View of Robot

Therefore, the axes of rotation in the joints of the robot need to be aligned with the axes of rotation in the hand. The above design allows the axes of the finger and thumb joints to be aligned closely with the corresponding joints in the hand. The MCP, CMC, MP and IP joints on the robot can line up directly with the corresponding joints on the patient. Since the PIP and DIP joints are combined on the robot, they can be closely aligned with the patient's PIP joint while the force is transmitted distally, moving both the PIP and DIP joints.

This design utilizes a cable drive transmission system to actuate the rotation out near the fingers with low endpoint inertia. A direct drive system would require having motors directly mounted at the joints and would be heavy and cumbersome.

5.2 Design Parameters

Most of the design parameters that the design needs to fulfill were discussed in Chapter 4. However, there are a few more that should be mentioned before the design details are discussed.

5.2.1 Forces

Using a variety of information from published research, personal experimentation and specifications of other devices, it was possible to choose what forces the robot should be able to provide to the patient. The forces listed in Table 5.1 are maximum forces. They would allow the patient to accomplish almost any functional task and could counteract the tone and spasticity commonly found in stroke patients. These force values are not necessarily maximum values for a normal person, since there is a concern that such high forces might injure the patient. In addition, most of the time the force provided will be lower than the listed values.

Once the transmission and other subsystems were designed, these forces were converted to necessary torques so that the motor specifications could be determined (see

Joint	Max Force
Fingers MCP	50 N
Fingers PIP	25 N
Index MCP	30 N
Index PIP	15 N
Thumb CMC	45 N
Thumb MP	30 N
Thumb IP	30 N

Table 5.1: Chosen Design Forces

Section 5.5.3).

5.3 Mechanism of Rotation

The first design decision that needed to be made was just how to rotate the joints of the robot. The rotations needed to be aligned with the patient's hand as mentioned above. They also needed to provide the desired ranges of motion. There were three main options for the axial rotation, each with a different amount of precision and kinematic constraint.

5.3.1 Options

A pin joint has a very specific axis of rotation, though as a result it is very confining kinematically. Adding a slider to a pin joint allows the axes of rotation to traverse along a specified direction as external forces act on the axis, giving it a degree of freedom the simple pin joint does not have. Finally, a flexure joint bends at an axis anywhere along a specified plane.

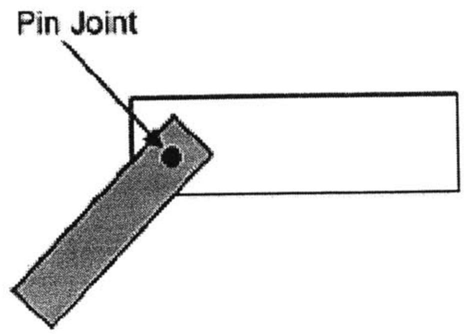


Figure 5-2: A Simple Pin Joint

Pin Joints

A pin joint, also known as a revolute joint, is where the rotation of two bodies is constrained to move only around one axis. Figure 5-2 shows an example.

As shown in Section 6.1, pin joints were used in the first prototype of the robot design. These did allow for the desired range of rotation and aligned with the axes of the fingers if the patient was the correct size. The problem with the pin joints was that if the patient's digit lengths were different than those prescribed for the robot, the joints would not line up and moving the patient was uncomfortable. Also, pin joints keep the axes of rotation at a fixed distance to one another. Since the PIP and DIP joints are combined in this design, the second fingers axis of rotation actually moves relative to the first during movements such as composite flexion (see Figure 5-3).

Pin and Slider

Adding a slider to the pin joint allows the joint to move along a line as it rotates (see Figure 5-4). This can be used to add adjustability to the location of the joints and the distance between them. However, it also adds complexity to the design. Having a slider at every pin joint would make the robot quite bulky and would be difficult to implement well.

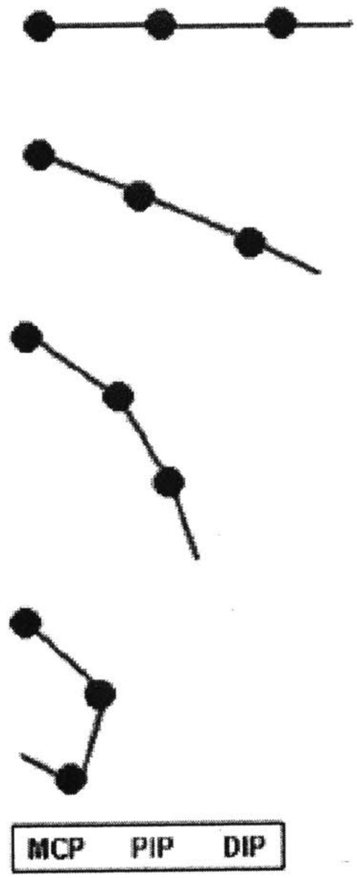


Figure 5-3: Schematic of Composite Flexion

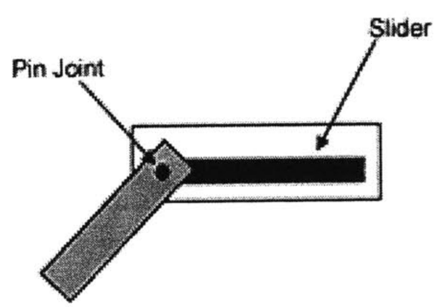


Figure 5-4: A Pin and Slider Joint

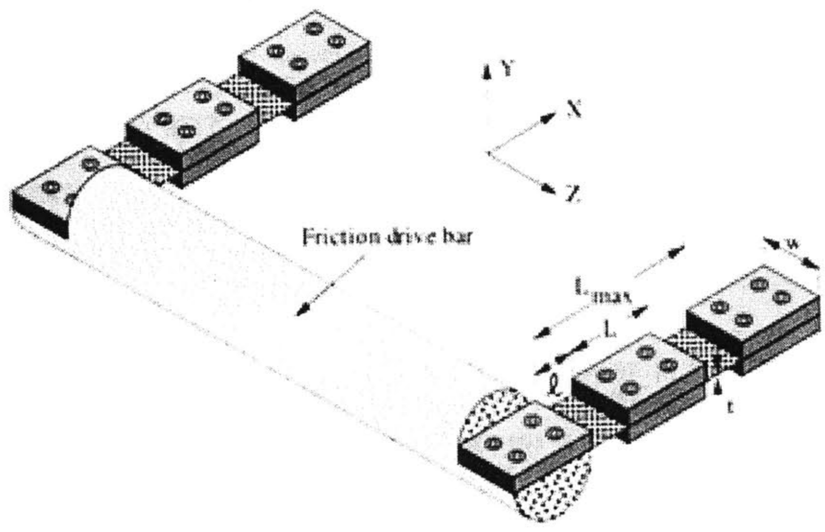


Figure 5-5: Example of a Clamped Flexure [38]

Flexure Joints

The final option for rotating the joints is to use a flexure joint. In this case, a clamped flexure provides stiffness in two of the three translational directions. In the third direction bending can happen and therefore there is rotation about an axis across the flexure and perpendicular to the bending. See Figure 5-5 for an example.

The main advantage of a flexure joint is that it can bend anywhere along its length, providing adjustability in the location of the axis of rotation. Therefore, when placed next to the patient's finger, the kinematics of the finger will determine the kinematics of the robot joint. This prevents patient discomfort or mechanical damage due to misaligned axes of rotation. Also, the flexure is very simple to design and implement. There are no bearings or moving parts to cause friction. If the flexure should fail, the clamps simply have to be removed and a new flexure put in place.

Another advantage of the flexures is that they allow use of a differential transmission system. The specifics of the transmission choice will be described below. The basic idea, however, is that by pushing or pulling on the top or bottom of the clamp section, rotation of the flexure can be achieved. This allows for rotation in both directions with only a

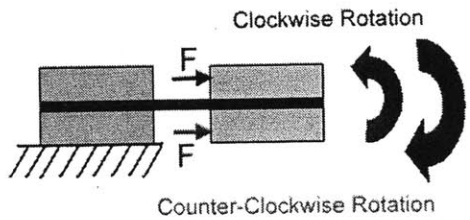


Figure 5-6: Forces and Resulting Rotations on Generic Flexure

force on the clamp as shown in Figure 5-6.

5.3.2 Flexure Details

Proof of Concept

A simple flexure prototype, shown in Figure 5-7, was constructed using 0.030" Teflon to prove the concept of using flexures to provide joint rotation. This mock-up proved that rotation of the flexure could be achieved by holding one clamp stationary and pushing or pulling above the flexure on the second clamp. It also showed that the Teflon had some shape memory, and the flexure did not always return all the way back to its original position. This particular flexure had little torsional stiffness although the bending stiffness in the non-desired directions was good.

This original type of flexure was incorporated into the second prototype of the robot (see Section 6.2). In this version, the flexures were made out of 0.030" thick Delrin to try and eliminate the shape memory of the Teflon. The Delrin did do this, however the formulation of Delrin used was found to be rather brittle and not as easy to bend as the Teflon.

In order to increase the torsional stiffness of the flexure, a "beaded" flexure was manufactured (see Figure 5-8). This flexure had alternating thick and thin sections. The thin

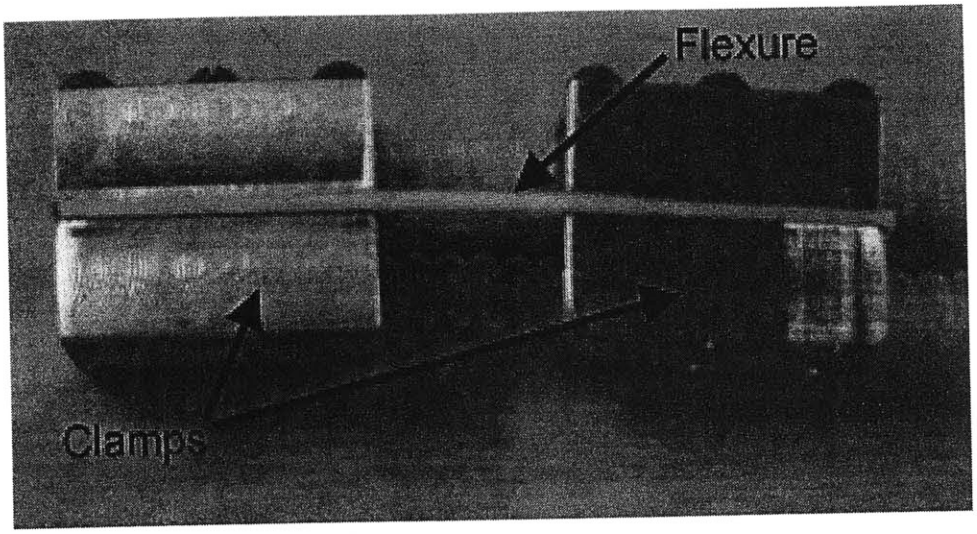


Figure 5-7: Proof of Flexure Concept

sections allowed for bending at several locations, while the thick regions provide torsional stiffness.

The beaded flexure was significantly stiffer in torsion than the original prototypes. However it was also more difficult to bend. Therefore, for the final design, it was determined that the thin section would be made thinner to allow for easier bending. Also, the thick section would be made thinner to allow for more angle of bend between the individual thick sections.

The calculations used to determine the material and various stiffnesses are discussed below.

Bending

The stiffness of a normal flexure is direction dependent, and the various equations are given below. The x direction is in compression, the y direction is the bending direction and the z direction is the sideways direction (see Figure 5-5).

$$K_x = \frac{wtE}{2l} \tag{5.1}$$

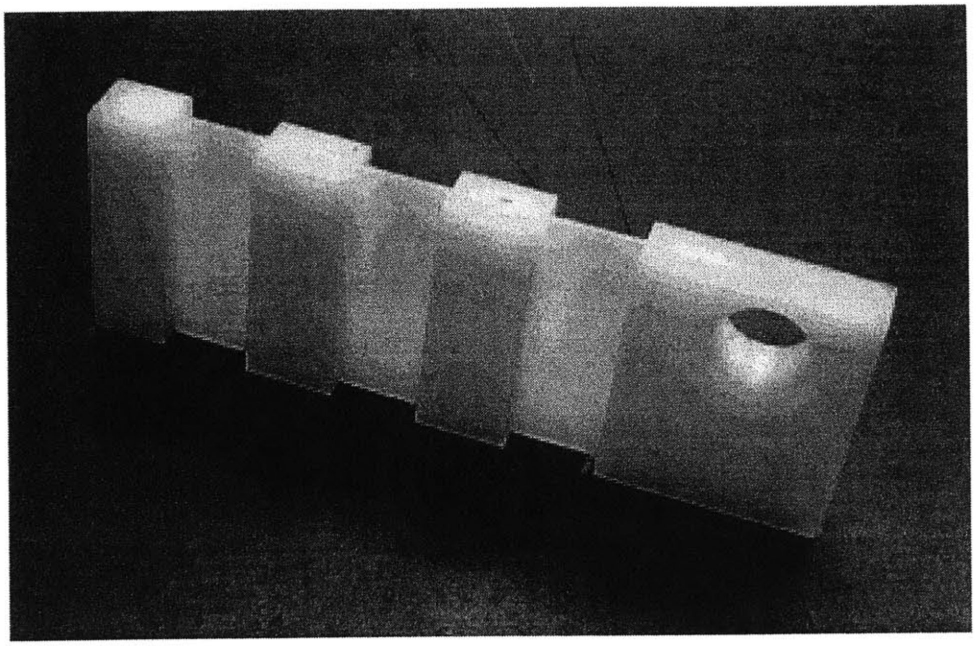


Figure 5-8: Beaded Flexure

$$K_y = \frac{2EI_{zz}}{l^2[\frac{2l}{3} + \frac{L}{2}] + \frac{2lt^2(1+\nu)}{5}} \tag{5.2}$$

$$K_z = \frac{2EI_{yy}}{l^2[\frac{2l}{3} + \frac{L}{2}] + \frac{2lw^2(1+\nu)}{5}} \tag{5.3}$$

where w is the width of the flexure, t is the thickness of the flexure, l is the length of the flexure, L is the length of the clamp, ν is the Poisson's ratio and E is the Young's modulus of the flexure and

$$I_{zz} = \frac{wt^3}{12} \tag{5.4}$$

$$I_{yy} = \frac{tw^3}{12} \tag{5.5}$$

The beaded flexure in Figure 5-8 can be likened to s series of clamps and flexures as in Figure 5-5, where l is the length of the thin section and L is the length of the thick section.

Torsion

In general, the torsional stiffness of a beam is given by

$$K_t = \frac{GI_p}{L} \tag{5.6}$$

where G is the shear modulus of the material, I_p is the polar moment of inertia of the beam cross-section and L is the length of the beam [20]. The compliance is given by the reciprocal, or

$$C_t = \frac{1}{K_t} = \frac{L}{GI_p} \tag{5.7}$$

In the case of a beam of multiple cross-sections, the torsional stiffness is given by [20].

$$\frac{1}{K_t} = \sum_{i=1}^{n} \frac{L_i}{G_i I_{p_i}} \tag{5.8}$$

In the case of the beaded flexure, K_t for each section was computed and then the above equation was used to obtain K_t for the total beam.

Buckling

Another strength concern was the buckling of the flexure. In the case of a cable or belt drive, often the drive element is pre-tensioned to avoid slippage. This pre-tension would put a resulting force on the flexure, possibly causing it to buckle. Modeling the flexure as a column clamped at both ends, the maximum force the flexure can take without buckling, P_{crit}, is given by

$$P_{crit} = \frac{\pi^2 EI}{L_{eff}^2} \tag{5.9}$$

$$L_{eff} = 0.5L \tag{5.10}$$

where I is the moment of inertia, L is the length of the beam and E is the Young's modulus . In the case of the finger flexure the buckling force is about 33 N and for the thumb flexure it is approximately 22 N. Therefore, although a pre-tensioned system could be used, the tension, T, would have to be relatively low.

$$T < \frac{Pcrit}{2} \tag{5.11}$$

One alternative in such a system is to rigidly connect the drive element to the pulley and then eliminate any slack so that any rotation of the pulley moves the drive element but the system is not in significant tension when in its neutral position.

Material and Fatigue

Although many plastics will allow for the bending required by the flexure, there are few that will not fatigue rapidly. Nylon is a common material used for living hinges and similar applications. In bending, the stress at the extreme fiber of the material, is given by

$$\sigma = \frac{Et}{2R} \tag{5.12}$$

where t is the thickness of the flexure or hinge, R is the radius to which it is being bent and E is the Young's modulus [3]. In the case of a 90° bend,

$$R = \frac{2L}{\pi} \tag{5.13}$$

where L is the length of the flexure.

Chosen Dimensions

Using the above equations in a spreadsheet format (see Appendix B) it was possible to optimize the flexure dimensions to obtain a low bending stiffness in the desired direction and a high torsional stiffness.

The elastic bending stress which results is 5176.49 psi. The yield strength of the Nylon 6/6 used is 12,400 psi so the material is not at the risk of yield. Fatigue data predicts that the flexure will have a life of approximately 10,000 cycles [42].

Clamping

The clamping of the flexure is pretty straightforward. There is a top and bottom section to each clamp. A bolt between the halves and through the flexure squeezes the clamp down on the flexure, preventing movement. The constraint in this design was the size of the clamp.

The bottom half clamp needed to have enough room for the transmission system but if it was too high, the rotation of the joint in flexion would be limited. The equation

$$\frac{\Theta}{360}\pi h = L \tag{5.14}$$

gives the maximum height of the clamp h given the angle of rotation Θ in degrees and the length of the flexure L.

For extension the height constraint was on the top half of the clamp. However, since for most joints extension is less than flexion, it was less of a concern. The index finger pieces were an exception since they needed to be tall enough to clear all the other fingers when only the index finger was actuated in flexion. In order to decrease the height, thereby allowing more extension and reducing the inertia of the hardware, the piece was angled back at 45 degrees. This angle was chosen because it is very difficult to rotate the MCP joint of the index finger more than 45 degrees without moving the other fingers.

5.3.3 Slider Details

Although the flexures allow for most of the joint rotations needed for the robot, abduction/adduction of the thumb CMC joint can not easily be accomplished by this mechanism. As mentioned earlier (Section 3.1.2), the CMC has two degrees of freedom: flexion/extension and abduction/adduction. Although the two axes of rotation are not coincident, they are close, and it would be difficult to put two flexures in the same space. Also, abduction/adduction is a rotation about an axis almost in the middle of the hand, which is not accessible. Therefore, in order to accomplish the second degree of freedom,

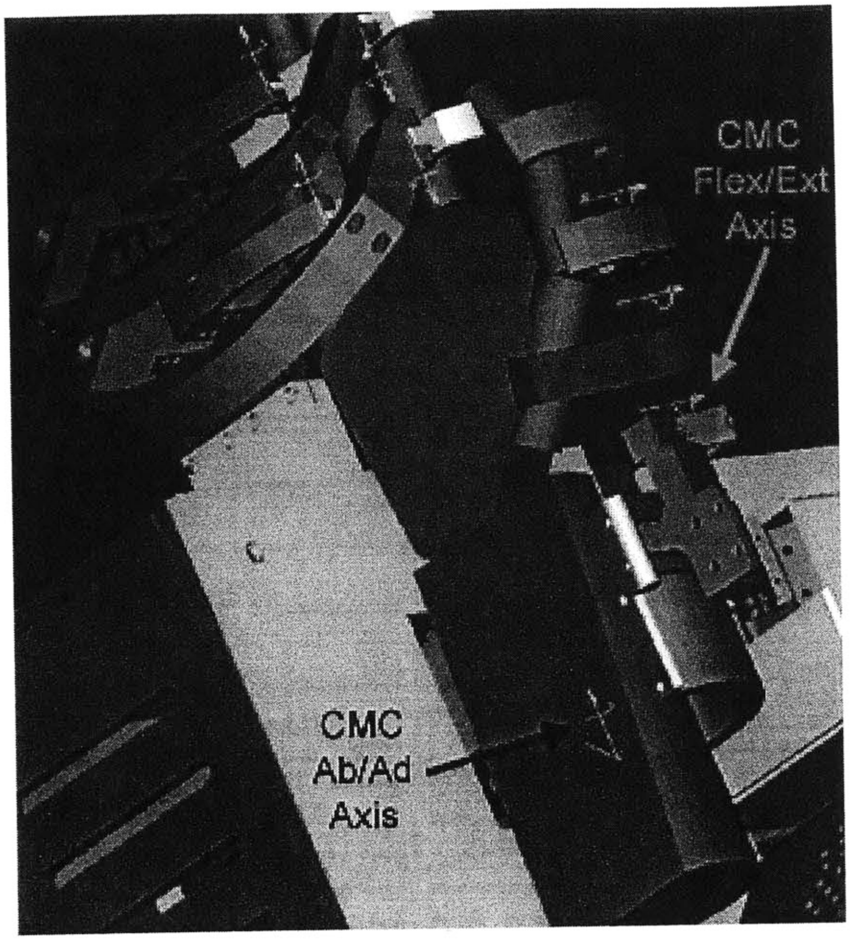


Figure 5-9: Location of CMC Abduction/Adduction and Flexion/Extension Axes on Robot

a slider mechanism was devised.

In this mechanism, the first clamp of the CMC flexion/extension flexure rotates around the axis of the wrist along a curved linear guide. Figure 5-9 shows the resulting axes of rotation for the CMC. Due to the size constraints, a sliding bearing was chosen over a roller design. The bearing has a back-to-back configuration to obtain higher stiffness (see Figure 5-10). The geometry, shown in Figure 5-11, is designed to constrain the slider in all necessary directions while keeping contact forces low. Also, the length of the bearing is more than twice the width of the bearing in order to prevent jamming.

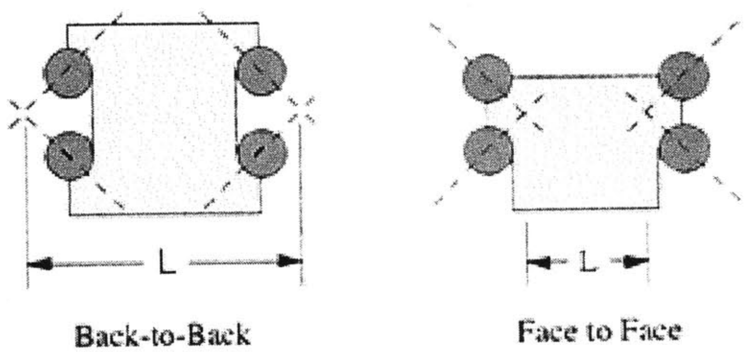


Figure 5-10: Effective Width for Resistance to Moments for Back-to-Back and Face-to-Face Configurations [38]

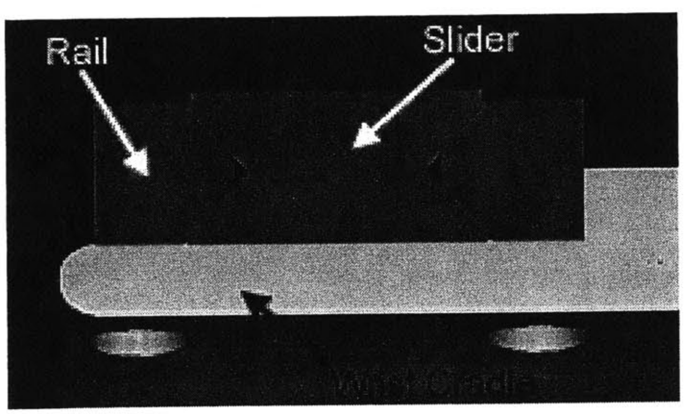


Figure 5-11: Slider Cross-Section

Materials

The materials chosen for the sliding bearing were 303 Stainless steel for the external "rails" and Delrin for the internal carriage. The coefficient of friction of Delrin on steel is 0.20 for static friction and 0.35 for dynamic friction [9]. The rails mount to the aluminum wrist cradle, while the carriage mounts to the aluminum clamp for the CMC flexure. This design allows the hardware to stay relatively lightweight while addressing tribology concerns about the bearing surface materials. Also, the modularity allows individual elements to be replaced relatively cheaply if necessary.

5.4 Transmission

As mentioned earlier, in order to prevent the robot from being very bulky, a transmission system was deemed necessary early on in the design. There are several methods of transmitting power, however, and this was the most thought-provoking design decision.

5.4.1 Options

The decision to use flexures constrained the transmission either (1) to push and pull at one point above the flexure or (2) to push/pull above and below the flexure alternatively. The options that were considered included using push/pull rods, integrating a type of hydraulic actuator (spring return, bellows or rolling diaphragm actuator) or implementing a drive system (belt, tape or cable).

Push/Pull Rods

One of the stiffest methods of transmitting force is to use push or pull rods. These rods are usually attached to a rotary or linear actuator at one end and to a lever arm on the other (see Figure 5-12).

The major disadvantages of this design are that it is bulky and complex. Also, it is difficult to have the actuator movement match the movement of the other end of the

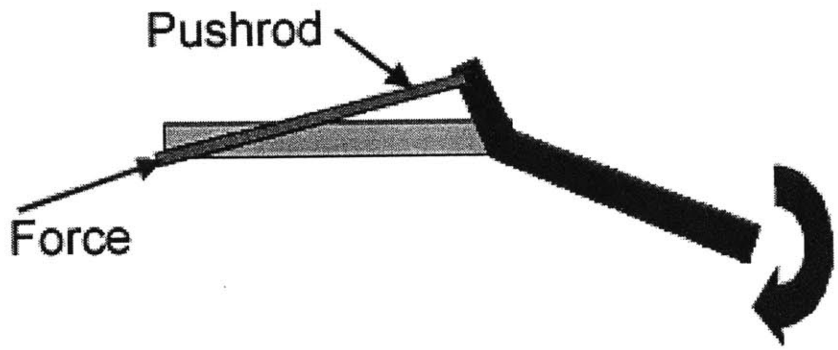


Figure 5-12: Example of a Push Rod Causing Rotation

rod. The mechanism must be carefully constrained to provide the correct magnitude and direction of forces.

Hydraulic Bellows

The first option for hydraulic actuation was the use of bellows. In this design, a bellows is located above and below the flexure. Remote from the robot, at the originating end of the hydraulic line, are two more bellows. When one of these remote bellows is compressed by a linear actuator or similar device, the displaced fluid travels through the line and the same volume is displaced in the second bellows next to the flexure, as shown in Figure 5-13. This displacement provides a pushing force on the clamp, bending the flexure and rotating the joint. The rotation of the joint compresses the bellows on the other side of the flexure (see Figure 5-14). The resulting displaced fluid travels backwards through the second hydraulic line, extending the remote bellows on that line and back-driving the actuator attached to that bellows.

One of the major advantages of this design is that there is no significant mechanical friction; the fluid speeds are low enough to not result in significant losses. Also, like all the hydraulic options, large forces can be transmitted in small cross-sectional area tubes. Finally since the bellows can compress to very small lengths they can fit between the two

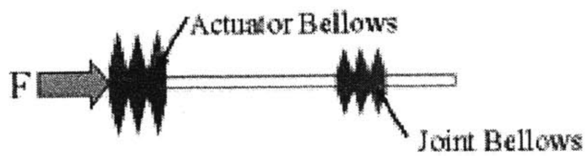


Figure 5-13: Double Bellows for Transmission of Force

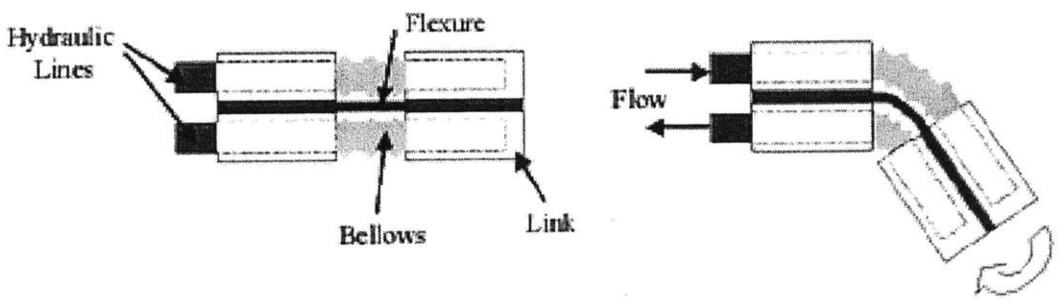


Figure 5-14: Flexure Rotation Using Hydraulic Bellows

flexure clamps even with a large angle of rotation (and therefore a small space between the two interior clamp edges).

This design does have some disadvantages however. First, there is compliance in the fluid and the bellows which can have a destabilizing effect on the system dynamics. More importantly, the system is slow overall. The transmission of force from the remote actuator to the clamp is only as fast as the fluid transmission speed. Finally, the major concern was constraining the bellows such that (1) it only expands in the longitudinal direction and (2) it does not "squirm".

The first concern, that of limiting the direction of the bellows displacement, can be solved relatively easily. Having convolutions in the bellows encourages it to expand longitudinally more than radially. The second problem is more difficult to get around. Squirm is the case where the pressure inside the bellows causes a sort of buckling and the bellows takes on a "S" shape. Although the bellows may be physically able to take a large

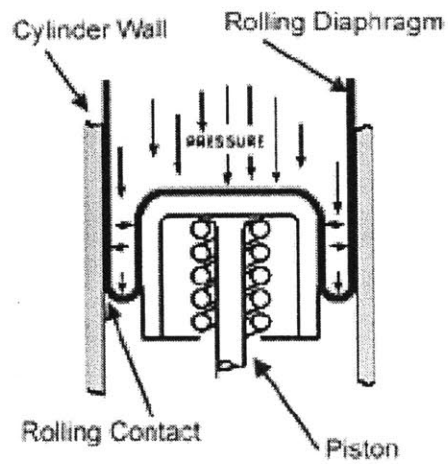


Figure 5-15: Rolling Diaphragm Actuator Technology, adapted from [7]

pressure without expanding radially and/or failing, squirm can happen at relatively low pressures.

Using data from a miniature bellows manufacturer (Miniflex Corporation), a stainless steel bellows of the desired size has a squirm pressure of only 330psi. A plastic or rubber bellows, which would be necessary to get sufficient compression during bending, would have an even lower squirm pressure. The pressure necessary to provide the specified force would almost definitely be higher than the squirm pressure. Therefore, other linear hydraulic actuators were researched.

Hydraulic Rolling Diaphragms Actuators

Linear hydraulic actuators as a whole have several disadvantages. First of all, position control is non-trivial. They are usually on or off. Secondly, they have a tendency to leak. Lastly, friction is generally high since the piston seal rubs on the wall of the cylinder.

Rolling diaphragm actuators (RDA) resolve this last problem. In RDA's, the piston seal is replaced by a flexible diaphragm. This diaphragm is rigidly attached to both the piston and the cylinder and moves with the piston, rolling along the wall, practically eliminating friction (see Figure 5-15).

In order to replace the bellows with RDA's, the actuators would have to be attached to the flexure clamps with pin joints in order for them to rotate with the flexure. However, since the actuators have a significant length even when compressed, there is not room for an actuator above and below the flexure.

Spring Return

A method of getting around the space constraint is to eliminate one of the actuators. The spring return actuator is a way to do this and is the simplest of the hydraulic actuator systems considered.

In this design scheme, a hydraulic actuator pushes the second clamp of the flexure in order to provide one direction of rotation. This push is against a spring force that returns the flexure to a pre-determined position when the hydraulic force is released. If the actuated rotation is flexion (clockwise in Figure 5-6), the actuator can be above the flexure. Extension is a smaller range of motion; therefore, the clamp edges are not all the way together and there is space for the compressed actuator . The fact that only one of the directions of rotation is actuated is a major disadvantage of the design.

Eventually, it was determined that none of the hydraulic actuation schemes were really feasible without great complexity and many custom-made parts. Therefore other, more conventional, methods of transmission were considered.

Belt Drive

One of the oldest transmission systems is that of using belts to transmit torque. The belt is wrapped around a drive pulley at one end, which is connected to a rotary motor, and is attached to another driven pulley at the other end. There are several incarnations of the belt drive including v-belts, timing belts, metal tapes and timing chains. The advantage of the system is that it allows torque to be transmitted over long distances between otherwise decoupled shafts.

One disadvantage is that there is usually compliance in the belt which can cause a loss of efficiency or create unexpected natural frequencies in the system. Also, as mentioned earlier, most belt drives need to be pre-tensioned to allow the torque to be transmitted. Finally, the main disadvantage in the case of a betl drive is that the path from the drive pulley to the driven pulley needs to be straight and unobstructed.

Cable Drive

Although cables can be used in push/pull systems such as in bicycle brake lines, they are most often used in rotary systems. Such a system is similar to a belt drive, but wire rope or cable is used as the driven element. The main advantage of the cable over the belt is that a cable can be routed through and around obstacles. The more interfaces the cable has with its surroundings, the greater the friction in the system. Even with this friction, however, the cable can still transmit force. Like the belt drive, the cable drive has an inherent compliance which can be detrimental to the system dynamics. In the case of this design, that worry is outweighed by the advantage of being able to transmit force through a complicated path. Wire rope is extremely strong for its size, so the cable drive can be very compact.

In the robot design the cable is rigidly connected to the drive pulley to avoid having to highly pre-tension the system. The cable end passes into the drive pulley where it is secured using a stop. The distance to the stop can be adjusted using a screw, thereby allowing slack in the system to be eliminated. The cable also must be mounted carefully to avoid unwinding during load.

As the drive pulley rotates, the cable pulls either above or below the flexure, depending on the direction of rotation. This rotation also provides slack to the opposite side of the flexure. Thus the flexure bends and the torque from the motor is transmitted out to the patient's finger (see Figure 5-16). Each clamp has two cables above and two cables below the flexure so that the tension force is even and twist of the flexure does not occur.

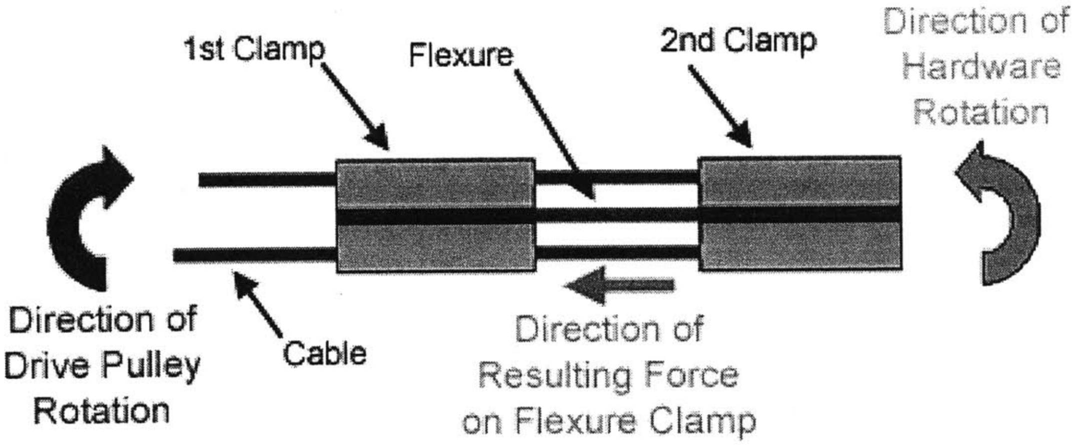


Figure 5-16: Schematic of the Cable Drive Transmission

5.4.2 Cable Drive Details

Material and Strength

One of the big advantages to using a cable drive is that a lot of force can be transmitted by a small cable. For that reason a stainless steel cable was desired. A 7x19 construction was chosen to maximize the cross-sectional area of the cable for a given diameter. In this construction, seven wires of 19 strands each are wound to create the cable.

The 1050SN cable from Sava Industries has a minimum breaking strength of 270 lbf which is greater than four times the expected force on the cable at maximum torque. This safety factor is consistent with cable use in industry [23]. Stress strain curve data from the manufacturer gives a measured Young's modulus equal to 5.537e6 psi.

Even though in tension the cable is more than strong enough, there is also the concern of the stress on the cable as it passes over the pulley and the edges of the housing holes. When the flexure joint is fully bent, the cable will be pressed up against the edge of the exit hole with significant force over a small area. Therefore all holes through which the cable passes have funneled openings to increase the area over which the force is distributed.

General pulley design information recommends that to maximize life for a 7x19 construction, the pulley diameter should be greater than 16 times and ideally should be 25

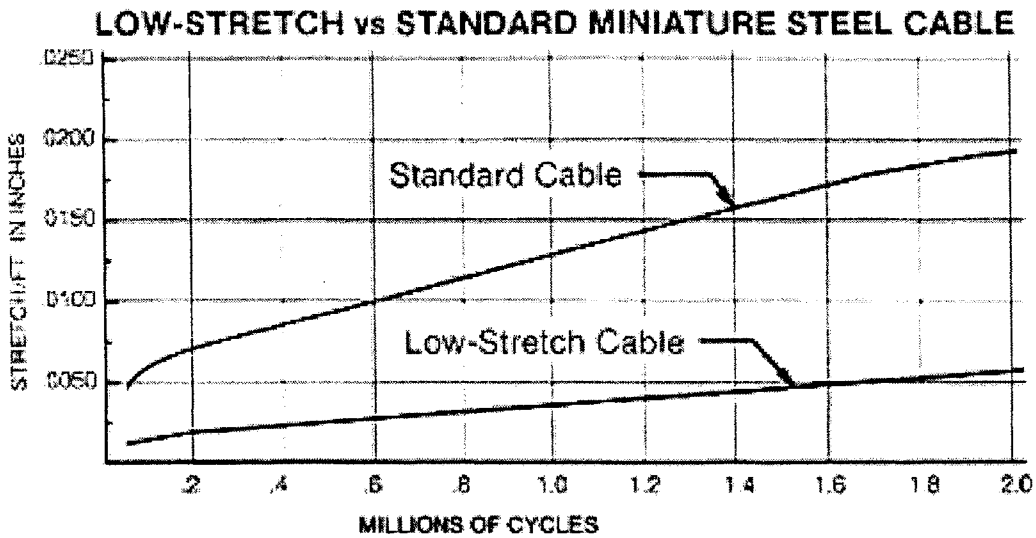


Figure 5-17: Cable Stretch Data from Sava Industries

times the uncoated cable diameter. For the chosen cable the uncoated diameter is 0.048", giving a minimum pulley diameter of 0.768" and an ideal pulley diameter of 1.2". Due to size constraints on the motor boxes, four of the eight drive pulleys are 0.875" in diameter. The rest are 1.125" in diameter. The pulley diameter also affects the effective strength of the cable. The ratio of the pulley diameter to the cable diameter determines the percentage of catalog strength the cable will have. For the small pulleys this ratio is 18.23, giving an effective strength of 90% the catalog strength, or 243 lbf. The large pulleys have a ratio of 23.44, resulting in an effective strength of 91.5%, or 247 lbf [36]. Both values are acceptable for this design. All of the fittings for the cable are also rated to at least 200 lbf in tension.

Stretch

As mentioned above, one of the biggest problems with a cable drive system is the compliance in the cable. For that reason, a low stretch cable from Sava Industries was chosen. Figure 5-17 shows the difference between the low stretch cable and a normal miniature steel cable.

Routing

Another problem inherent to the cable drive system designed is friction. Since the robot is serially actuated, the cable for the PIP joint must pass through the MCP joint and the base before reaching its end connection. Thus, the further out the joint is on the robot, the more obstructions the cable has to pass through and the higher the friction. For this reason, although the necessary actuation force is lower at the outer joints since less inertia is being moved, the additional friction may eliminate this advantage. The chosen motors can provide more than the required torque for all joints in case there is additional or unexpected friction.

Other design choices were also made in an attempt to reduce friction. Choosing a nylon coated cable running through aluminum housings provides a good bearing surface for the cable. Also, the housing holes are a little oversized to allow some freedom of movement for the cable, while still providing support for the cable. Finally, as mentioned above, the edges of the holes are countersunk. This not only reduces the stress on the cable but also the friction since the normal force is reduced.

The other significant problem with routing for the cable was that when the flexure bends in flexion, the top cable will have to extend more than the bottom cable is pulled back. To eliminate this the cables are crossed from top to bottom in the middle of the joint. This causes the deflection of both cables to be the same. However it presents a new problem since there is a flexure between the two cables. Either the flexure needed to be made narrower, with the cables passing on either side, or slots had to be cut in the flexure to allow the cables to pass.

Using Pro/Mechanica's finite element analysis (FEA) ability, it was possible to determine the difference in bending and torsional strength between the two designs. Figures 5-18 and 5-19 show the resulting stresses and deflections for the bending case. The slotted flexure was stronger than the narrow flexure in both bending and torsion. Since there is a concern that the weight of the hardware might bend the flexures if they are too weak and torsional stiffness is vital, the slotted flexure design was used. The slots were rounded at each end to avoid stress concentrations present at corners.

5.5 Actuation

The method of actuation for the robot is highly dependent on the method of transmission, but since several transmission systems were considered, so were several methods of actuation. With the cable drive system either a linear actuator or a rotary actuator could be used. The linear actuator would pull directly on the cable and thus on the flexure. Conversely, the rotary actuator rotates the drive pulley, thus pulling on the flexure. The main constraints were the amount of displacement that was necessary in the cable and the force that needed to be provided. Actuation also needed to be back-drivable in accordance with the functional requirements of the robot.

5.5.1 Linear Options

Linear actuators are becoming more prevalent in machine design, and there are several technologies that can now provide accurate linear positioning. The options considered were piezoelectric actuators, DC linear motors, solenoids, moving magnet actuators and rotary to linear systems such as a rack and pinion or lead screw and stepper motor.

Piezoelectric Actuators

The biggest drawback to piezoelectric actuators is their limited stroke length. Cedrat Recherche has overcome that problem by manufacturing amplified piezoelectric actuators (see Figure 5-20). In these actuators a specially designed external cage amplifies the motion of the piezo to obtain strokes up to $500\mu m$. When the hydraulic bellows transmission was being considered this would have been sufficient, however with the cable drive it is not. The actuators can be stacked serially to provide greater displacements but this is very cost prohibitive.

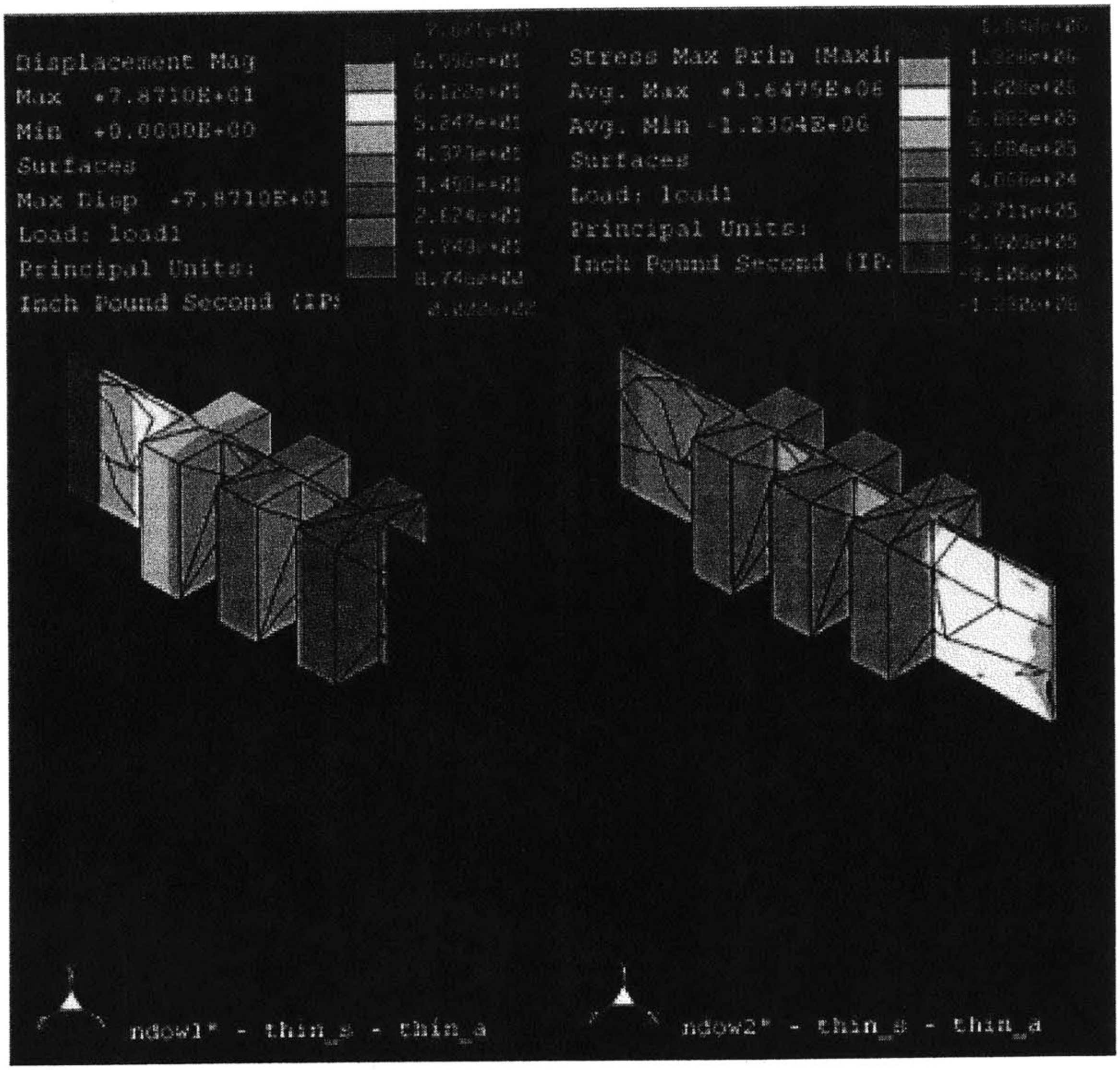


Figure 5-18: Stress and Deflection of Narrow Flexure

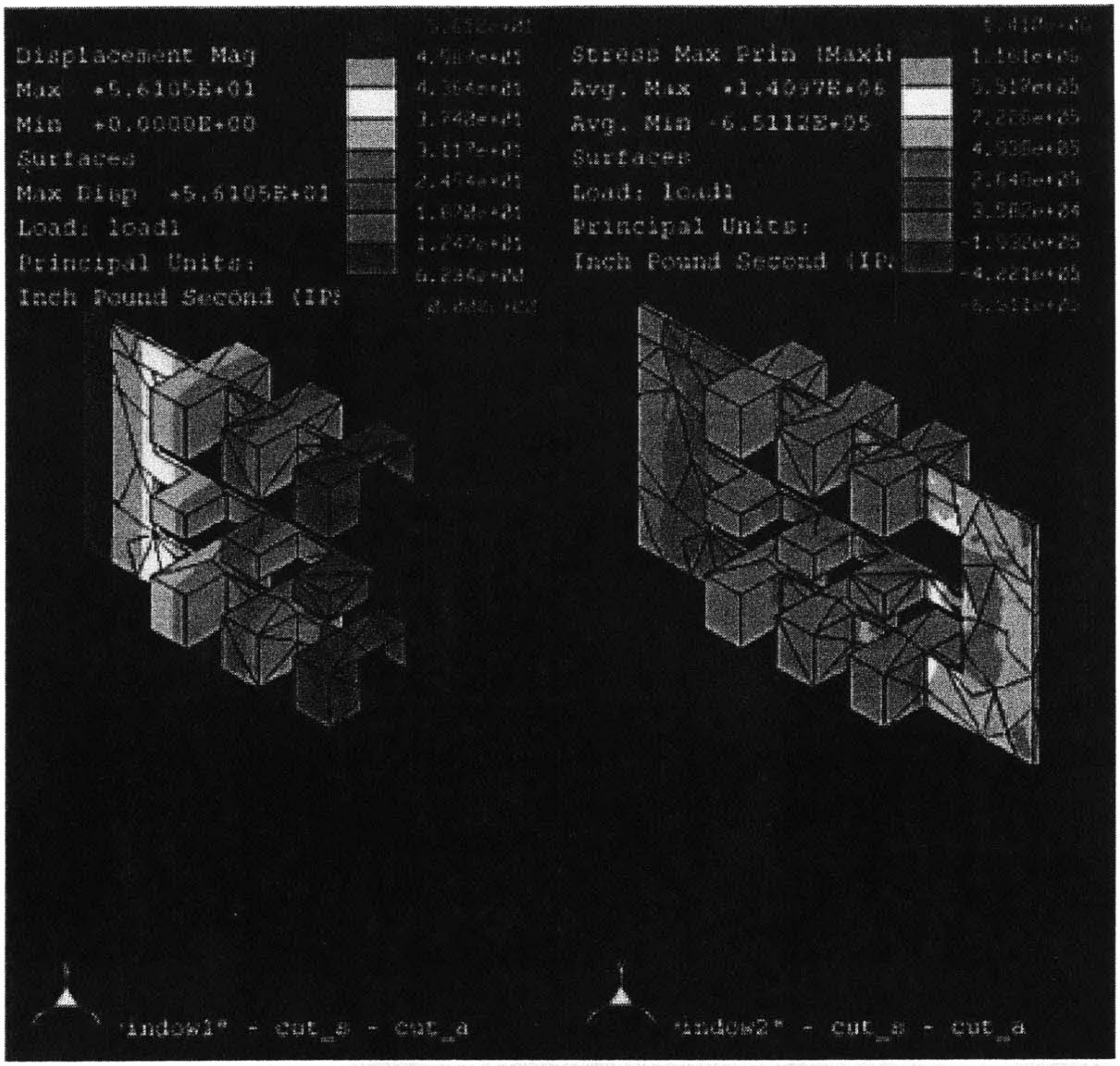


Figure 5-19: Stress and Deflection of Slotted Flexure

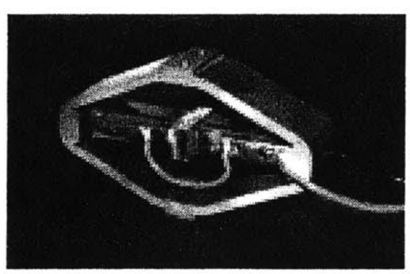


Figure 5-20: An Amplified Piezo Actuator (Cedrat Recherche)

DC Linear Motors

A more standard linear technology is the DC linear motor. Similar to a rotary motor, an iron core moves in relation to an electromagnetic field. In the case of a linear motor, the core is the carriage and the electromagnetic field is created in the track. The positioning can be very accurate when used with a linear encoder. DC linear motors come in a wide range of strokes and forces. However, the relative size of the motor to the stroke length is high. Therefore it was determined that linear motors would be too bulky for a design focused on being small and unobtrusive.

Solenoids

Another long-standing linear technology is the solenoid. Like the piezoelectric actuator, solenoids are limited in stroke. They also do not provide a constant force along their stroke. The push/pull force is proportional to how much of the core is inside the housing. For these reasons, solenoids were not desirable for this design.

Moving Magnet Actuators

With a moving magnet actuator, a permanent magnet is fixed to the center yoke and the stator contains an electromagnet. The yoke moves up and down inside the stator as it is energized (see Figure 5-21). The advantages of the moving magnet actuator are that the force is constant regardless of position and is proportional to the input current. Unfortunately, the strokes and forces are too small for this application.

Rotary to Linear Actuators

Finally, using a rotary to linear conversion was considered. Two options were a rack and pinion or a miniature lead screw on a stepper motor. Both systems can provide significant stroke lengths in a small package. With the stepper motor system, force is a concern since most small stepper motors do not have high torque. Unfortunately, both systems have a good deal of backlash which was undesirable.

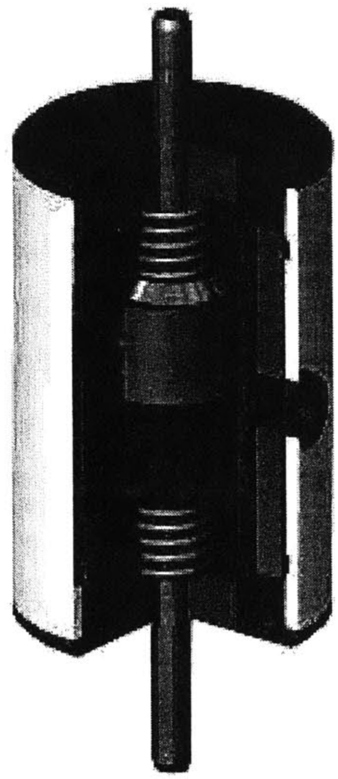


Figure 5-21: A Moving Magnet Actuator (Moving Magnet Technologies)

5.5.2 Rotary Options

Using the cable drive transmission system encouraged the use of rotary acutators. Once the limitations of the linear actuation options were determined, rotary options became even more important. Two main rotary options were considered: solenoids and DC motors.

Solenoids

The rotary solenoids have similar concerns as the linear ones. Rotation is fixed, and usually limited. It is possible to get solenoids with various positions or stops but usually there are only two or three. This would limit the number of joint angles the robot could achieve. Therefore the idea of using a rotary solenoid was discarded.

DC Motors

Inside the category of DC rotary motors, there is the further breakdown of brushed versus brushless motors. Both can provide large torques in a relatively small package. Also, since the technology is very established, there are many feedback devices which can be used to provide precise position control. With brush motors, the largest concern is the friction of the brushes. The decision was made to use a Kollmorgen brushless motor.

5.5.3 Rotary DC Motor Design

Requirements

As mentioned earier, the transmission system and required forces had both already been chosen. Therefore, in order to determine the motor requirements, the necessary forces needed to be converted into necessary torques. These calculations can be found in Appendix B. The resulting required torques are shown in Table 5.2.

Since the torques are all in the same range, it was desirable to find one motor that could be used for all joints. This would not only standardize the mounting hardware but

Joint	Torque (in-lbs)	Torque (N-m)
Fingers MCP	20.686	2.337
Fingers PIP	27.196	3.071
Index MCP	15.666	1.770
Index PIP	20.742	2.343
Thumb CMC Flex/Ext	27.341	3.089
Thumb CMC Ab/Ad	26.051	2.943
Thumb MP	27.267	3.081
Thumb IP	27.267	3.081

Table 5.2: Necessary Motor Torques

would also keep the actuator characteristics consistent across the system. In practical terms, such a specialized motor is not usually a high volume item; ordering several can decrease the price and/or the lead time.

The other main requirement for the motor was that it be small in size. Using a transmission system allows the motors to be set away from the endpoints but they still need to be relatively close in order to avoid cable dynamics. Therefore compactness was a key issue.

Gear Ratio

As Table 5.2 shows, the torques the motors needed to provide were significant. Therefore a gear ratio was necessary to reduce motor size. Using a gear ratio necessarily decreases the back-drivability of the system. However, it was determined that using a ratio of 10:1 was a good compromise between necessary torque and back-drivability.

Adding a standard gearbox to the chosen motor generally increases the size of the package significantly. Therefore a single gear reduction was designed such that the small drive gear mounted on the motor shaft and the large gear mounted directly to the cable drive pulley. Hardened spur gears were used for the sake of simplicity and robustness.

Figure 5-22: The RBE motor from Kollmorgen

The result was that the motor needed to provide 0.31 Nm of torque for the maximum provided force.

Specifications

The motor chosen was the frameless brushless Kollmorgen RBE DC motor model number 1213 (see Figure 5-22). A frameless motor allowed for close integration between the motor and the housing and therefore a smaller package size. The RBE 1213 provides a continuous torque of 0.387 Nm. Slanted windings were specified to reduce cogging. Also, although the motor comes with Hall effect sensors, it was specified to interface with an encoder for more precise position control. See Appendix C for specifications.

Kollmorgen also makes servoamplifiers to interface with its RBE motors. The Servostar CD servoamplifier includes a integrated power supply and can directly interface with the encoder output from the motor. The 6 Amp model was chosen since at the maximum force the motor may draw up to 5 Amps of current. Details can be found in Appendix C.

Housing and Shaft Design

Kollmorgen provides a design guide for working with their frameless motors (see Figure 5-23). From this, the housings for the motor box were designed. The motors sit in a stepped housing and are held in place by a mounting ring. Manufacturing the housings out of aluminum allows them to act as heat sinks for the motors, thus lowering motor and box temperatures.

Since the motors are frameless they come without a shaft. The shaft design was also specified by Kollmorgen and was modified to allow the attachment of the drive gear using a pin hub. The torsional shear, τ_{max}, on the shaft can be calculated from

$$\tau_{max} = \frac{Tr}{I_p} \tag{5.15}$$

where T is the torque applied to the shaft, r is the shaft radius and I_p is the polar moment of inertia. From this calculation, it was possible to make sure the maximum stress on the shaft was less than the yield stress of the material. For the motor shaft the shear stress is about 9,000 psi and for the pulley shaft it is about 11,250 psi. The motor and pulley shafts were manufactured out of 303 Stainless steel which has a yield strength of 34,810 psi. Therefore both shafts are well outside the range of material yield. See Appendix D for full drawings of the housings and shafts.

5.6 Sensors

In order for the robot to be controlled and for patient data to be collected, various sensors were necessary. In terms of the patient, the most important piece of information is the angle of their joints. However, since this is not co-located with the motor, which is the system input, this information is non-ideal for control. Ideally, the angle of rotation of the motors, and therefore the drive pulleys, should also be measured. Finally, although it is not currently implemented in this prototype design, it would be desirable to know the force at the robot/human interface.

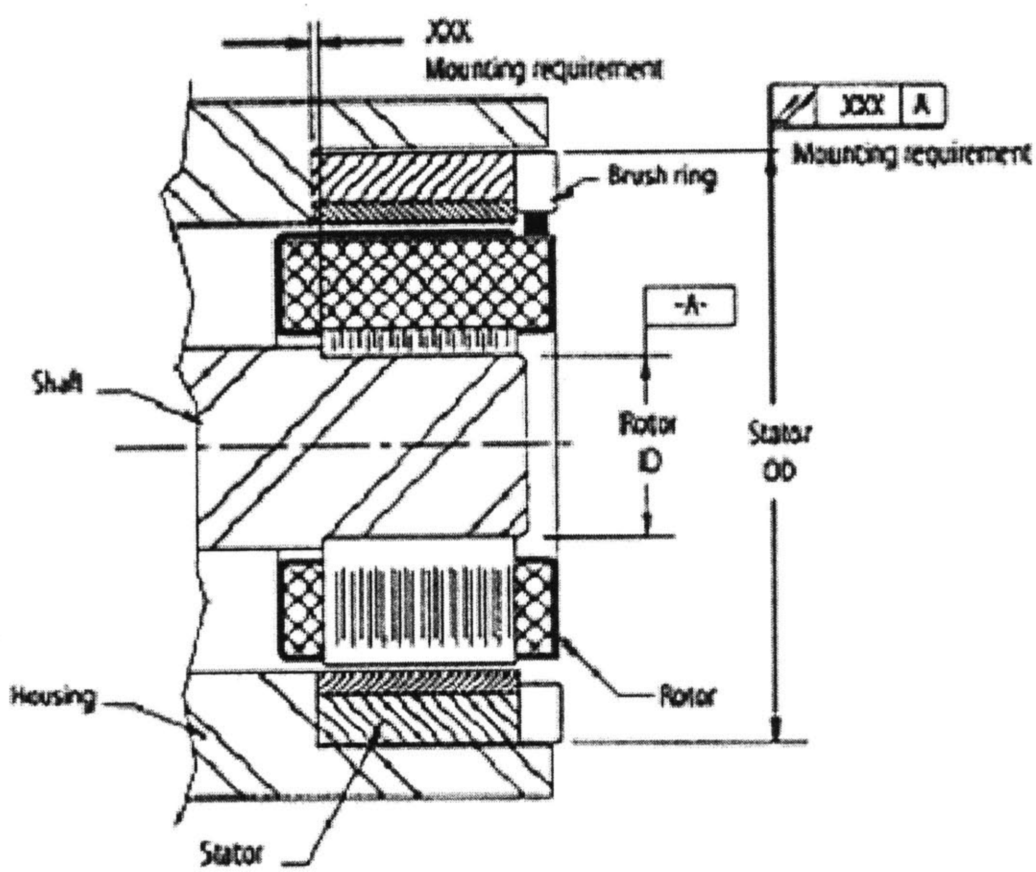


Figure 5-23: Frameless Motor Mounting from Kollmorgen

5.6.1 Joint Angle

Sensor Specifications

Finding a compact and simple way of measuring the joint angles was a challenge. Strain gages have been used in similar applications but they are difficult to mount and calibrate. Another option was the use of a fiberoptic device.

Measurand Inc. makes such a device. Their Miniature Shape Sensor (model number S720) can be mounted along the side of a rotating joint and measures the angle through which the joint travels (see Figure 5-24). A LED at the base of the sensor sends light down the fiber. The light bounces off the end of the measuring region and back to a light sensor. A decrease in light is proportional to the angle through which the sensor has bent and is output as a voltage. It is necessary to rigidly mount the sensor to the joint on both sides of the measuring region, equi-distant from the region. Putty is provided by the manufacturer for this use. The fiber can be made to any length; the measuring region is a constant distance from the end however. For the final prototype seven sensors were ordered. Three had 12" long leads for the thumb joints and the other four had 20" leads for the finger and index joints.

Testing and Calibration

Although the product information claims that the output voltage from the sensor is linear with angular deflection, it was desirable to actually test a sensor and find out. For this reason a test sensor of standard length was ordered and tested.

A simple jig was constructed to allow me to mount the sensor to a pin joint then rotate the joint through various angles (see Figures 5-25 and 5-26). The output was then read by a standard analog-to-digital (A/D) card and then analyzed. The sensor takes a 5 V input power supply and outputs a signal between 0 and 5 V.

Seven tests were run with the sensor jig. Before the testing began, samples of the output were taken at zero degrees; the gain and offset on the sensor were adjusted so

Figure 5-24: Miniature Shape Sensor by Measurand

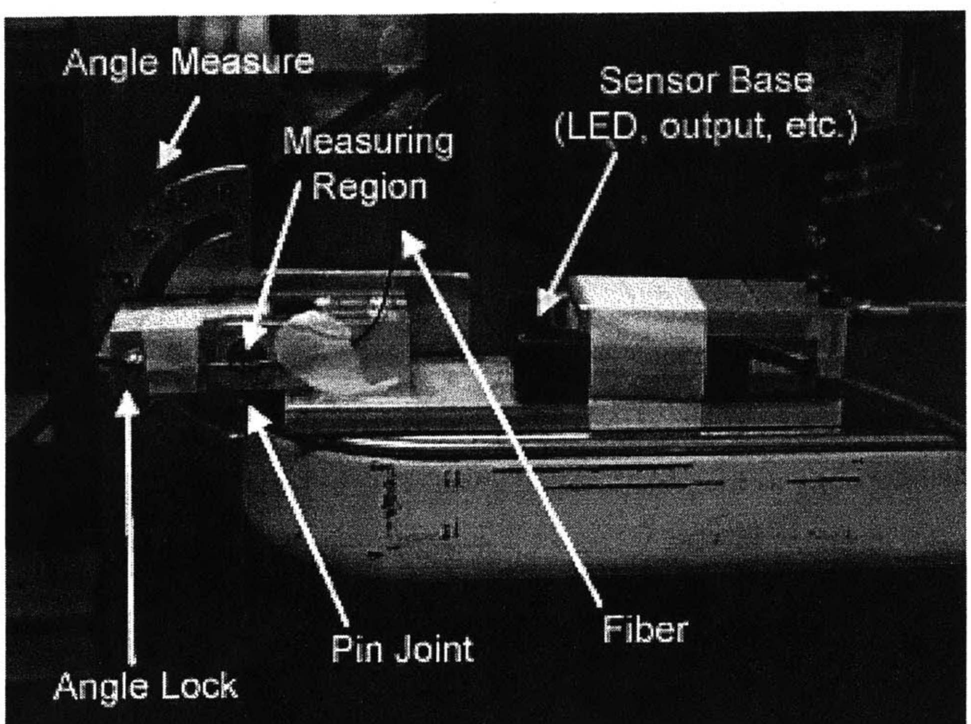


Figure 5-25: Shape Sensor Testing Jig

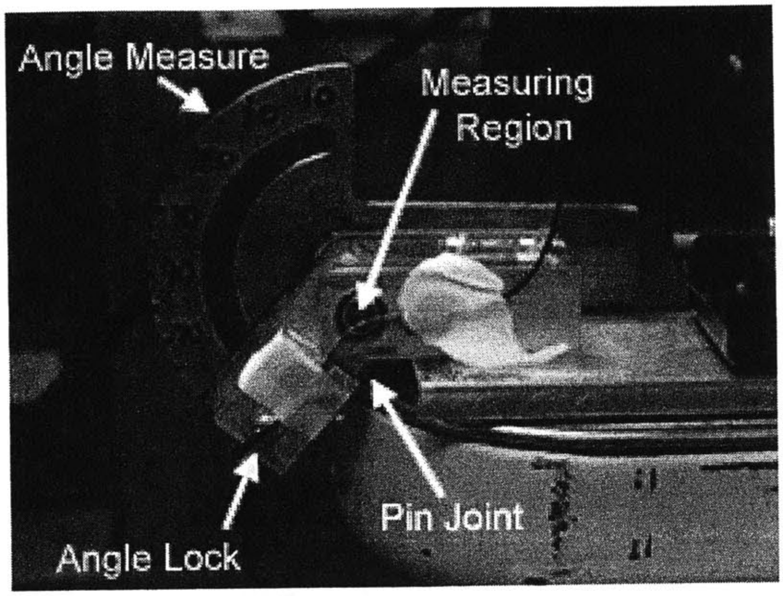


Figure 5-26: Close-Up of Testing Jig

that the zero position gave a reading of 2.5V. The first test was very encouraging due to the good linearity of the data. However, during the test the sensor came loose from the putty used to attach it to the jig. The sensor was re-attached using tape and the test was re-run. Linearity was similar but there was a significant offset from the first curve. After this run the sensor seemed to be saturating (tests three and four). The gain and offset were re-calibrated and tests five through seven were done. Between tests six and seven a wait of several minutes and a power down were performed to see if the sensor stayed consistent. The results of tests five through seven are shown in Figure 5-27.

As Figure 5-27 shows, the sensor output was fairly linear over the range of angles tested. The linear fit line follows the expression:

$$V = 0.0309\Theta + 2.3158 \tag{5.16}$$

with a R^2 value of 0.98. It is interesting to note that the non-linearities are centered around zero degrees. The section before zero is nicely linear. Then, after a small flat section, the output is again linear. This is possibly due to the sensitivity of the light sensor. When the angular deviation from zero is small, the difference in light the sensor

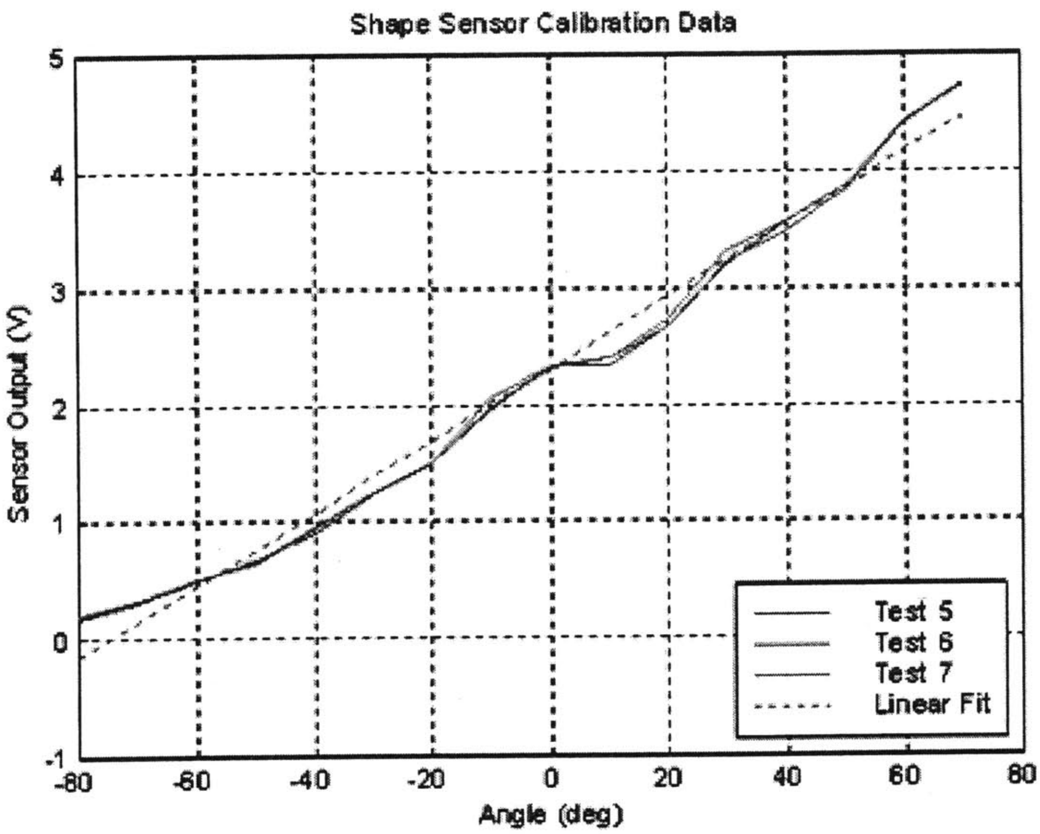


Figure 5-27: Sensor Testing Data

Figure 5-28: Hollow Shaft Encoder by Gurley Precision Instruments

receives is also small. Therefore, the light sensor may have difficulty resolving the change in light and outputs a zero reading for a few degrees before returning to a linear output. The most encouraging thing about this data was that although there are distinct non-linearities in the output, they are consistent across the tests and therefore can be predicted and compensation can be made.

5.6.2 Motor Angle of Rotation

A more established technology was used to determine the angle of motor rotation. An optical incremental encoder from Gurley Precision Instruments provides an index pulse and angular measurement (see Figure 5-28).

Sensor Specifications

Due to the 10:1 gear ratio, a 1 degree rotation of the motor shaft is equivalent to 0.1 degrees of rotation of the cable drive pulley. The rotation of the drive pulley is then converted to the deflection of the cable, s, by the equation

$$s = \frac{\pi}{180}\Theta r_{pulley} \tag{5.17}$$

where Θ is the rotation and r_{pulley} is the radius of the drive pulley. From geometry, it takes 0.009 inches of cable deflection to cause one degree of flexure joint rotation. Therefore a single degree of rotation of the motor shaft gives 0.085 degrees of joint rotation for the small drive pulley and 0.110 degrees for the large drive pulley.

The encoder resolution is also constrained by the servoamplifier. The maximum allowable frequency for the encoder input to the servoamplifier is 3 MHz. Therefore the maximum angular velocity the servoamplifier can handle is given by

$$\omega_{max} = \frac{frequency}{resolution} \tag{5.18}$$

and

$$resolution = 4(linecount)(interpolation) \tag{5.19}$$

The frequency used is 2 MHz to be safe, the line count is 1024 and the interpolation is 5. Therefore, ω_{max} equals 97.65 rev/s at the motor or 9.765 rev/s at the drive pulley. Assuming that the maximum frequency of human movement is 10 Hz over 2 cm, the minimum jerk profile gives a maximum velocity of 0.752 m/s. The maximum radius of rotation for the joint is equal to the length of the flexure plus half the width of the hardware, or 1.18" (3 cm). This gives a maximum joint angular velocity of 25.07 rad/s or 3.99 rev/s [29]. Therefore the servoamplifier will be able to easily handle any input the human patient gives the robot. The resulting resolution on the motor angle is 0.018 degrees, which is more than adequate.

5.6.3 Force Sensing

Finally, as mentioned above, in later versions of this robot force sensing will be necessary. This will most likely be in the form of a thin flexible force sensor which can be applied to the finger interfaces of the robot. Forces between the robot and the patient could then be measured. Steadlands International and Tekscan are two of the manufacturers that make

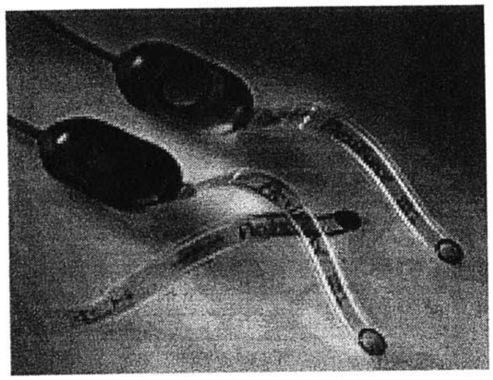


Figure 5-29: A Standard Flexible Force Sensor by Tekscan

such devices (see Figure 5-29). Since there are so many other aspects to this prototype and the force sensors are not integral to the robot, it did not make sense to also add force sensing until the system has been built and characterized.

5.7 Other Hardware

5.7.1 Motor Box

The motor boxes do just as the name suggests; they contain the motors. Their main function is to locate and provide housings for the eight Kollmorgen motors. One box contains the four motors for the fingers and index modules. Another contains the motors for the thumb CMC flexion/extension and MP joint. The last box has the motors for the thumb CMC abduction/adduction and the IP joint. Using the frameless motors allowed the boxes to be relatively compact. Also, since they are mounted underneath the robot they can be sunk into the therapy table and will not seem imposing to the patient. See Appendix D for complete drawings.

Thermal

The other main concern with the motor boxes besides size was temperature. Safety is the main concern in the design of the robot, and the risk of burn from the motor box is something to be considered. The maximum contact temperature a human can withstand for one minute is 60°C on uncoated metal and 85°C for plastic. For ten minutes, the limits are 50°C for metal and 60°C for plastic [28]. Using data from Kollmorgen and heat transfer theory the worst case temperature at the outer surface of the motor box, which is constructed of aluminum with a plastic face over it, is 56.24°. This is below the maximum temperature for one minute of contact. Since the patient should never be in contact with the boxes at all this was considered sufficient. This does not include the fact that all the motor boxes have vents on the non-patient facing sides to provide more air circulation and cooling.

5.7.2 Patient Interaction

How the robot interacts with the patient is just as important as the function of the robot. If the robot is not comfortable, patients and therapists will not want to use it, regardless of its potential benefits. There are two main areas where patient interaction occurs on the robot. The first is the wrist cradle and arm support. The second is the actual finger and thumb interfaces. The final concern regarding patient interaction is the adjustability of the robot.

Wrist/Arm Support

The wrist cradle and arm support are not actuated but they play a crucial role in keeping the patient comfortably in position during therapy. The arm rest at the back of the robot simply acts as a support for the forearm of the patient. It is padded and somewhat curved to provide a comfortable resting place. Straps could be added to immobilize the patient's arm if desired. The wrist cradle has a 200 degree curve in which the patient's wrist can rest. It also contains the base for the abduction/adduction slider.

The robot actuates the patient's hand in a sideways position. In order for the patient to get in and out of this position, the therapist simply has to pull the finger hardware out of the way and then angle the patient into the wrist cradle. Later versions may incorporate a lock to keep the hardware out of the way during patient entry and exit. The thumb module can simply be rotated down out of the way and then put up into position once the patient is in place.

The current prototype has padding in the cradle but no restraints. In actual use many patients will use a splint since extending the wrist to about 25 degrees improves the ability to move the fingers [10]. This splint can fit between the patient's wrist and the cradle. However it is also important to have the option for passive motion of the wrist especially during some functional tasks. In that case the patient would not have a splint, and the wrist cradle would act as the only constraint. For both these cases it would be desirable to have velcro straps across the cradle which could hold the patient's wrist in place with varying rigidity. These are easy to implement and can simply be mounted to the wrist cradle after manufacture.

Finger/Thumb Interfaces

The interfaces between the patient's digits and the robot are one of the most difficult things to design. The digits must be restrained such that forces from the robot can be transmitted to the patient without discomfort. Since every person is different, a generic but comfortable shape was necessary. Also, the size of the interfaces had to be such that the pressure on the patient's skin was not too high. A pressure of less than one psi is recommended for short term splinting applications [4].

The final result for the fingers was a flexible plastic interface with a gentle ergonomic curve. Mounting the interface on a pin through the hardware gives rotation to the interface, reducing overconstraint. The edges of the interface piece are curved and the whole piece is padded to eliminate discomfort as the robot rotates and helps the patient's digit rotate. Again, adjustable straps will be mounted to the interface to attach it to the patient. For the thumb, the pin mounted system was not feasible so ergonomic curves were added to the cantilever pieces. The CMC flexion/extension hardware acts like a clamshell shape gripping the patient's thenar prominence for motion. See Appendix D for drawings of the pieces.

Adjustability

As mentioned in the Section 3.1.4, patients are many different sizes and shapes. Making a robot that could adjust to all patients would add signifiacnt complexity to the robot. So it was decided that the first prototype would be for an average-size patient, and that once the robot design was characterized and critiqued, more sizes could eventually be produced. The design is scalable, with the main adjustability being in the length of the flexures but also in the length and height of the cantilever sections.

Finally, although the robot was designed for the left hand, it could easily be redesigned for the right hand. For the finger and thumb hardware, it is simply a matter of drilling the holes for the cable stops in the other side of the pieces. The motor boxes also do not need to change. The only significant change would be that the wrist cradle would have to be made with the features on the opposite side from where they currently are.

Chapter 6

Hardware

As the design of the robot progressed, various prototypes were made. They tested different methods of attachment to the patient, force transmission and rotation. Especially when dealing with ergonomic issues, nothing is better than being able to feel what the robot will be like on the patient. Design flaws and advantages were immediately apparent without the cost of time and money required for machining. Below is a discussion of the various prototypes and what problems they helped make apparent and solve.

6.1 First Prototype

The first prototype was made very early in the design process using a ZCorp three-dimensional printer. This printer uses a cornstarch based material which was then hardened using marine epoxy.

This prototype was the first test of putting the robot to the side of the hand and using cantilevers to reach the fingers. It also tested the idea of attaching to the end of the patient's fingers, much like many of the CPM devices (see Section 2.3.1). The prototype used pin joints for rotation. Figure 6-1 shows the finger module of the first prototype.

The PIP actuation occurs at the end of the fingers (the actual mounting to the fingers was not prototyped), while the MCP actuation is cantilevered out over the fingers. This

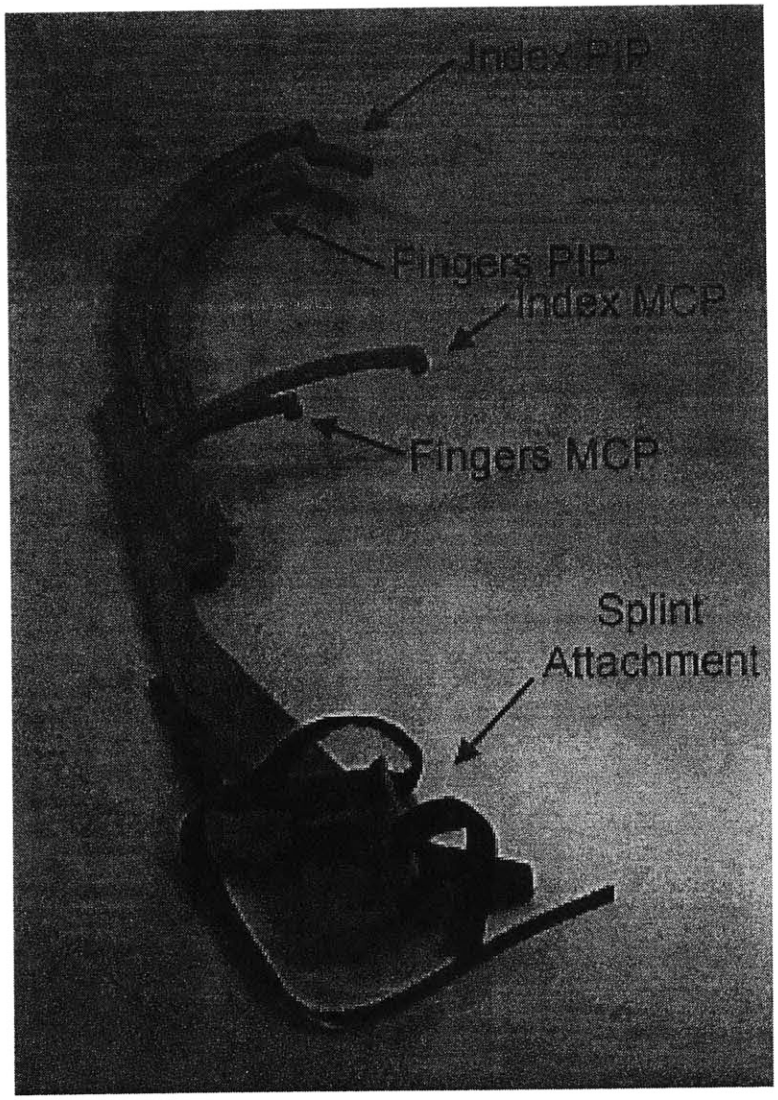


Figure 6-1: Finger Module of First Prototype

prototype proved that the end location for the PIP actuation got in the way of many functional tasks. The MCP actuation worked well except that the index MCP could not rotate very far without the fingers due to the low height of the cantilever. Also, this prototype proved that unless the patient's joints matched up very well with the pin joints of the robot, the mechanism was uncomfortable.

The thumb module is shown in Figure 6-2. Like the finger module it was designed to attach to a pre-existing splint at the wrist. This module was a test of using a slider around the wrist to provide thumb abduction/adduction. The principle was good but this implementation of two pins in slots did not work well. Therefore the slider was redesigned. The odd shapes of the thumb interfaces were an attempt to push on the thumb without encumbering movement. Unlike the finger module, the thumb joints of the robot are above the joints of the patient, rather than next to them. This method worked reasonably well so it was used in the next prototype as well.

6.2 Second Prototype

The second prototype came later in the design process after several modifications and improvements had been made to the design. It was used at a design review in the early Fall of 2000 as a tool to discuss remaining redesign issues. This prototype was manufactured using stereo-lithography technology, where a resin is hardened by a laser layer-by-layer to create the part. The parts are somewhat brittle but are fairly robust and could be drilled and sanded for assembly if necessary.

Figure 6-3 shows an overall view of the second prototype. This prototype implemented flexure joints for all flexion/extension DOF, and the wrist cradle has become integral with the finger and thumb modules. The height of the index finger cantilevers has been increased to allow them to pass over the other fingers. This time the finger interfaces were prototyped, and velcro straps were used to hold the interfaces to the fingers and thumb.

As in the first prototype, the thumb features are located on the outer side of the

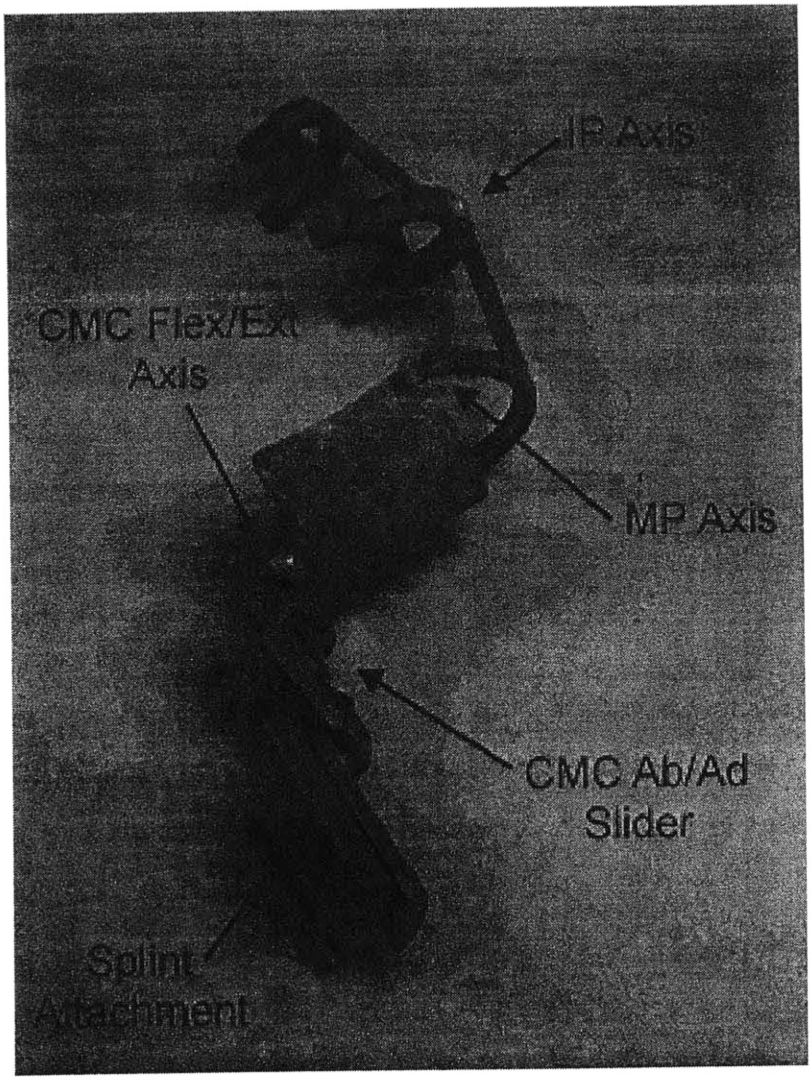


Figure 6-2: Thumb Module of First Prototype

thumb knuckles. This prototype proved that aligning the axes of rotation (as in the finger module) worked much better than locating them outward from the joints. This required redesign of the thumb module such that the axes of rotation were next to the anatomical ones, yet the hardware did not get in the way of functional tasks. The final prototype implements this new design.

Figure 6-4 is a close-up of the finger module. The holes in the hardware above and below the features were sized for a hydraulic transmission system (see Section 5.4.1). In this view it is possible to see how high the cantilevers are. It was later decided that this height could be reduced by angling the pieces. The finger interfaces with their ergonomic shape can also be seen in this view. These pieces turned out to be very comfortable for several people, except on the edges when the joints were at a large angle of rotation. Edge rounds and padding were added to the design as a result. The finger flexures worked quite well, providing a comfortable rotation of the finger joints without too much resistance. It became obvious the torsional stiffness needed to be increased however by using a beaded flexure.

Another view of the finger module from the side can be seen in Figure 6-5. This view shows that the hardware was heavy for the flexure design used, causing sag in the neutral position. Using the beaded flexure design should eliminate this problem.

Finally, Figure 6-6 shows a close-up of the thumb slider for the second prototype. A T-slot was used and worked well. The tolerance on the prototype made sanding and shaping necessary, but the rotation was possible, and the slider provided good abduction/adduction. Occasionally the slider would jam due to a poor length to width ratio; a flaw that was fixed in the final prototype.

6.3 Final Prototype

The final prototype is in the process of being manufactured and assembled. It will include all of the actuation, transmission and sensor elements described in Chapter 5. All parts

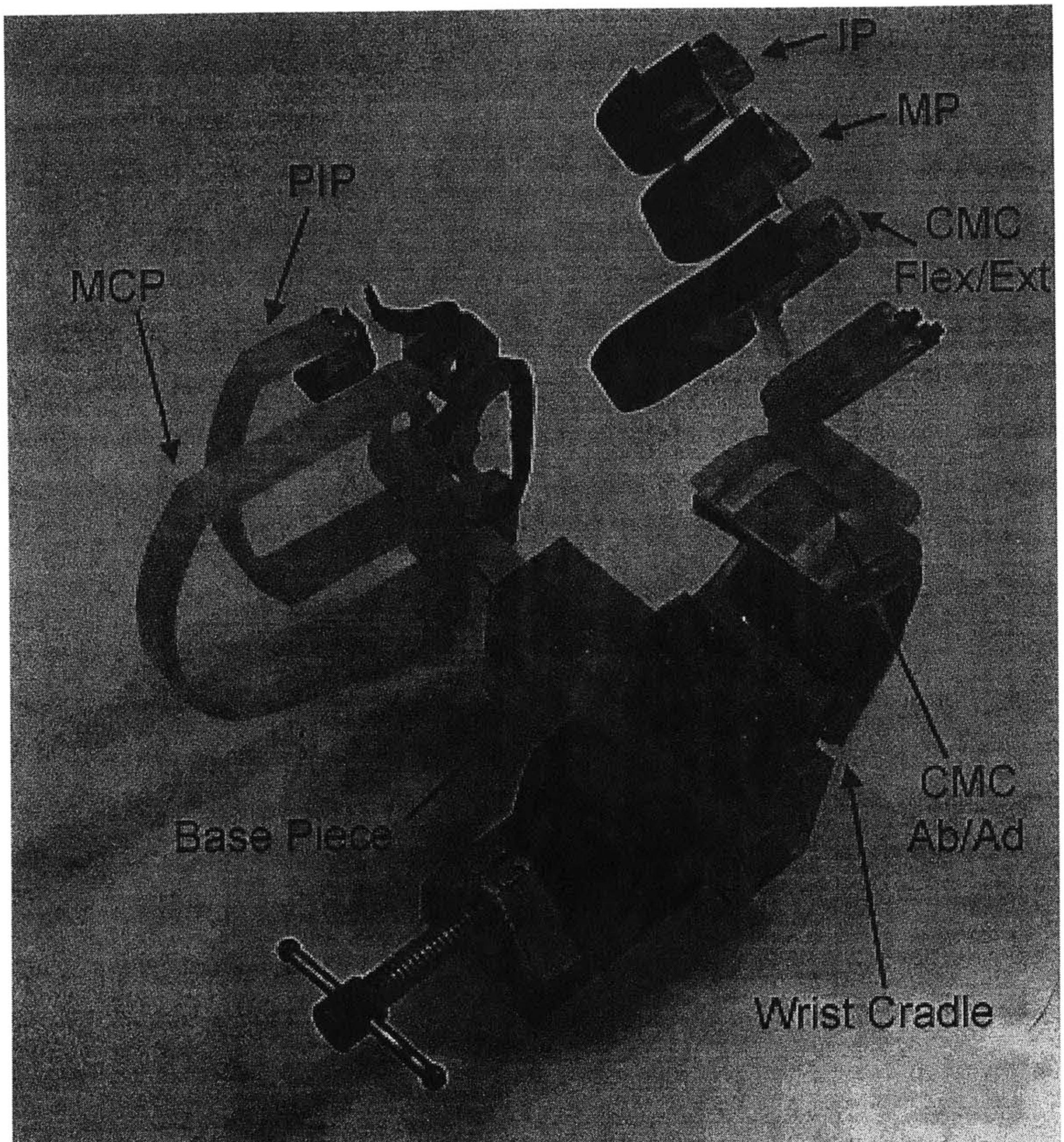


Figure 6-3: Second Prototype

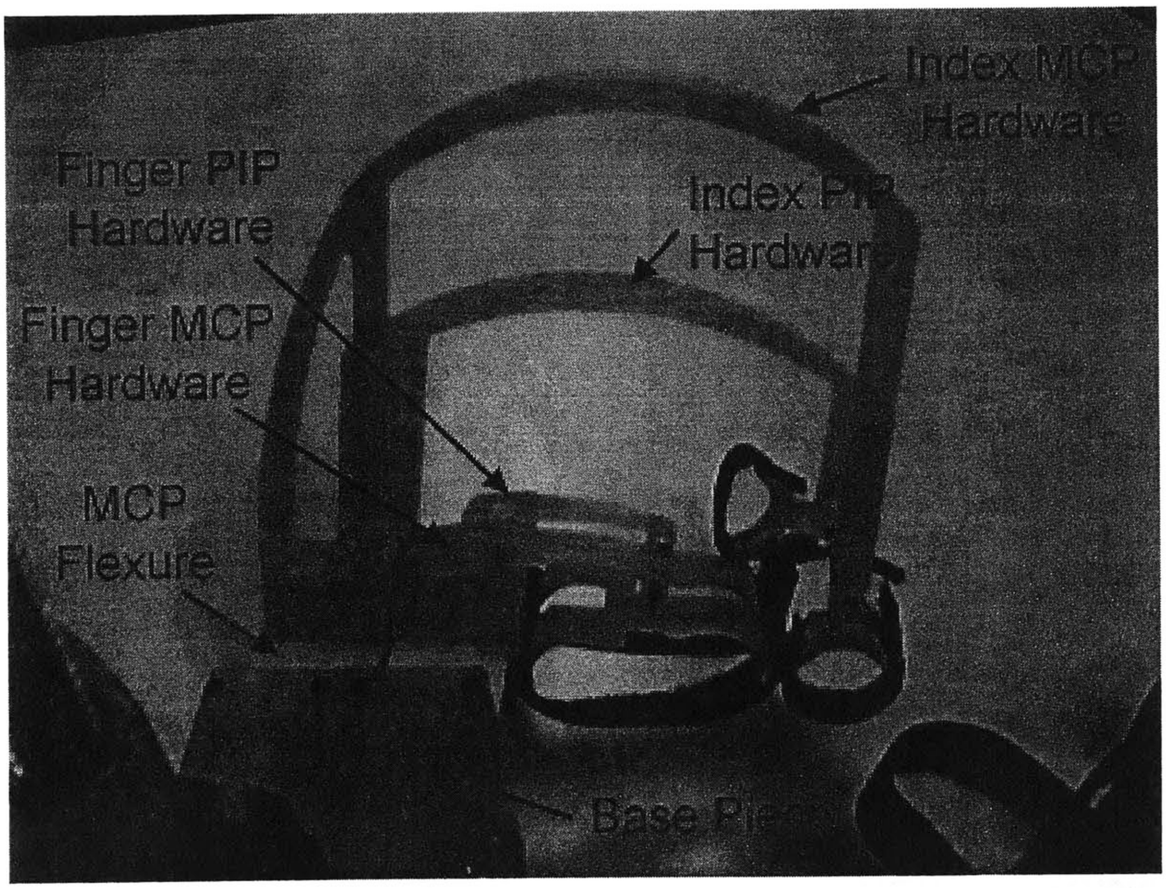


Figure 6-4: Finger Module of Second Prototype

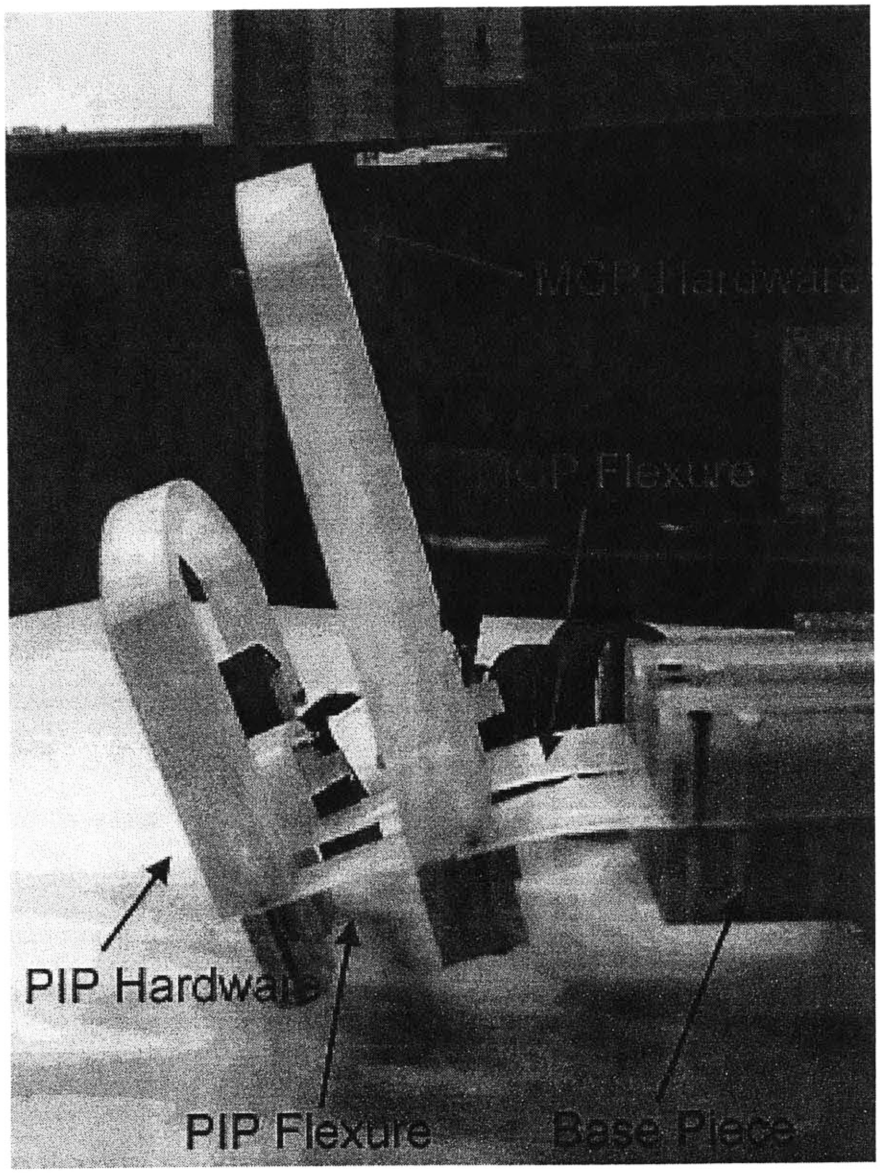


Figure 6-5: Side View of the Finger Module of Second Prototype

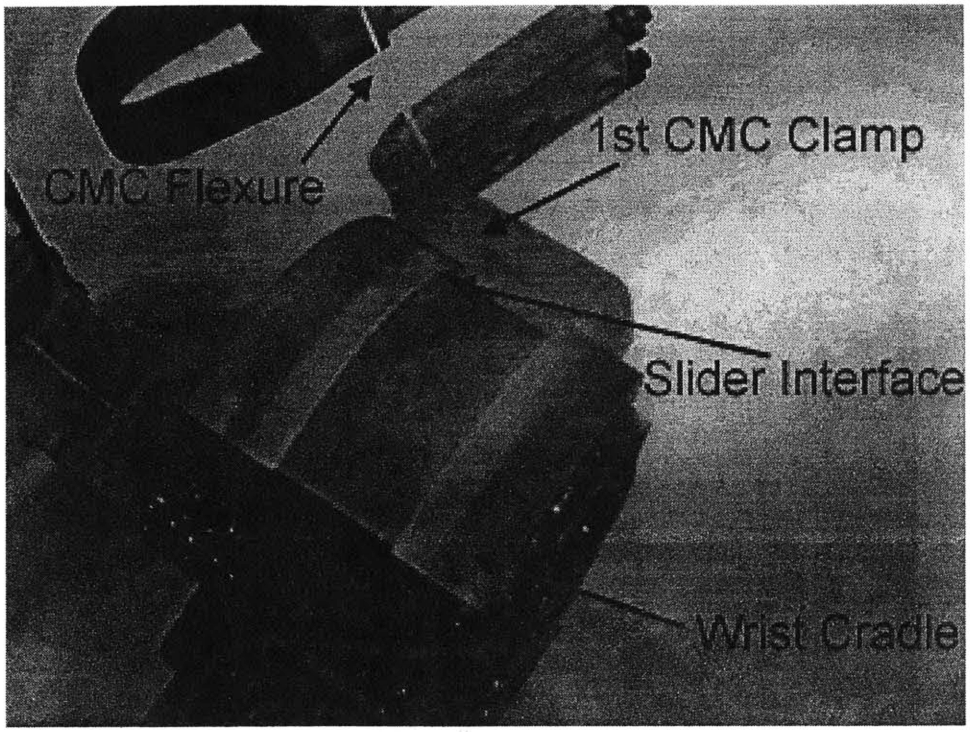


Figure 6-6: CMC Rotation in Second Prototype

are being manufactured from aluminum, except for the motor and pulley shafts and the finger interfaces. Aluminum is relatively cheap and is easy to machine. Also, it can be anodized or powder coated to create a colorful robot. Eventually many aluminum pieces could be replaced by injection molded plastic parts. The shafts are being made out of 303 Stainless steel for strength and the interfaces will be rapid prototyped using a flexible material. It may also be possible to experiment with integrating straps into the interfaces by using the prototyped pieces for urethane molding.

The flexures were manufactured in-house from Nylon 6/6 so that they could be tweaked if necessary to get just the right feel and performance. As designed, the flexures were easily bent in the desired direction but were torsionally stiff. The machining of the flexures, however, was a very time consuming process involving a CNC mill and milling saw. The nylon was fairly brittle in machining; once milled to the flexure thickness, it was impossible to cut the material without a very small-toothed saw. Also, the machining left numerous burrs where the nylon strands were cut. For these reasons, it is suggested that either Delrin or a flexible rapid prototyping material is used for the flexures in the next prototype.

Since the final prototype was not complete in time to be included in this thesis, solid models of the robot and the various assemblies will be used to describe the final design. The colors are not necessarily representative of how the final robot will look but are used to identify the modules. The hand in the model was constructed from average anthropometric data and can be placed in almost any possible configuration to simulate various grips and tasks.

Figure 6-7 shows an overall view of the robot. The motor boxes are mounted below the robot so they can be sunk into the table and not interfere with the patient. Bolting the arm rest into the table provides additional support for the patient. The finger and thumb modules are described in more detail below.

Figure 6-8 shows a close up of the hand-robot interfaces. The flexures are not included in the thumb module so that the rotation of the hardware can be seen. As mentioned above, the axes of rotation are now aligned with the joints of the patient.

The finger module assembly is shown in Figure 6-9. As mentioned in the discussion of the second prototype, the index hardware has been angled backwards to decrease the cantilever height. Each piece of index hardware consists of three pieces, which are assembled to create the cantilever. This simplifies the machining and reduces the material cost significantly. The finger interfaces are very similar to those used in the second prototype. Beaded flexures with slots cut into them for the cables are shown in between the hardware. The base piece is mounted to the motor boxes.

Finally, Figure 6-10 shows the thumb assembly, again without the flexures in place. The CMC abduction/adduction hardware is three pieces assembled together to simplify machining. The V-section of the slider is part of this hardware. The clamshell shape of the CMC flexion/extension hardware holds and moves the patient without straps since it is awkward and difficult to hold onto the first metacarpal of the thumb. The MP and

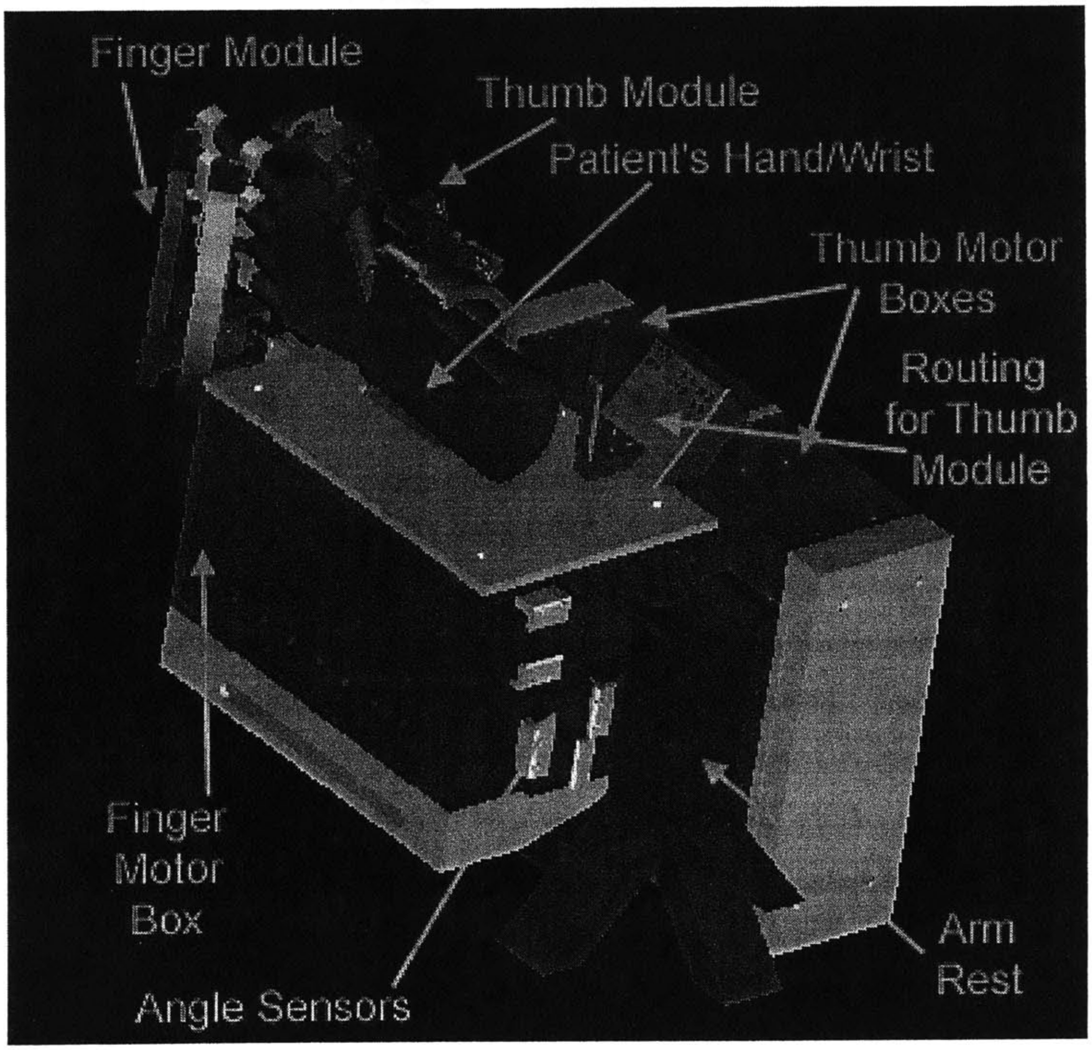


Figure 6-7: Solid Model of Entire Robot

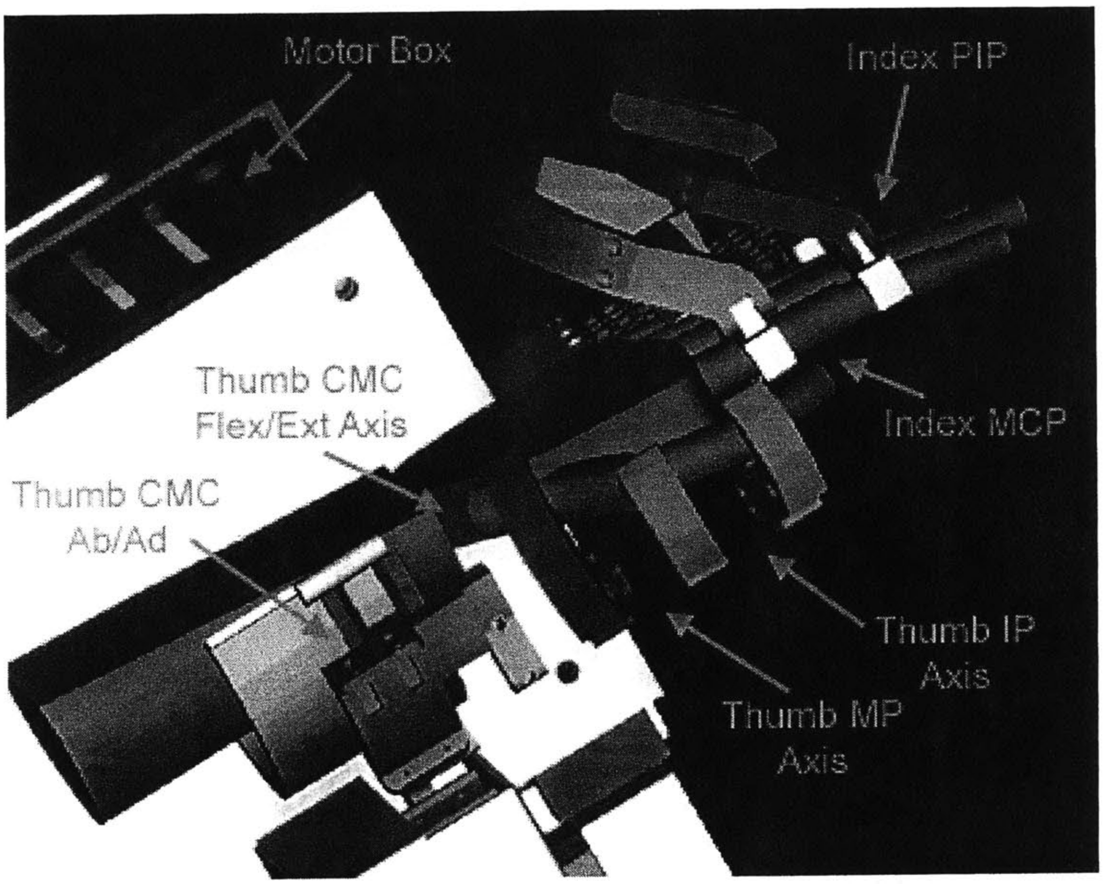


Figure 6-8: Close-Up of the Hand-Robot Interfaces

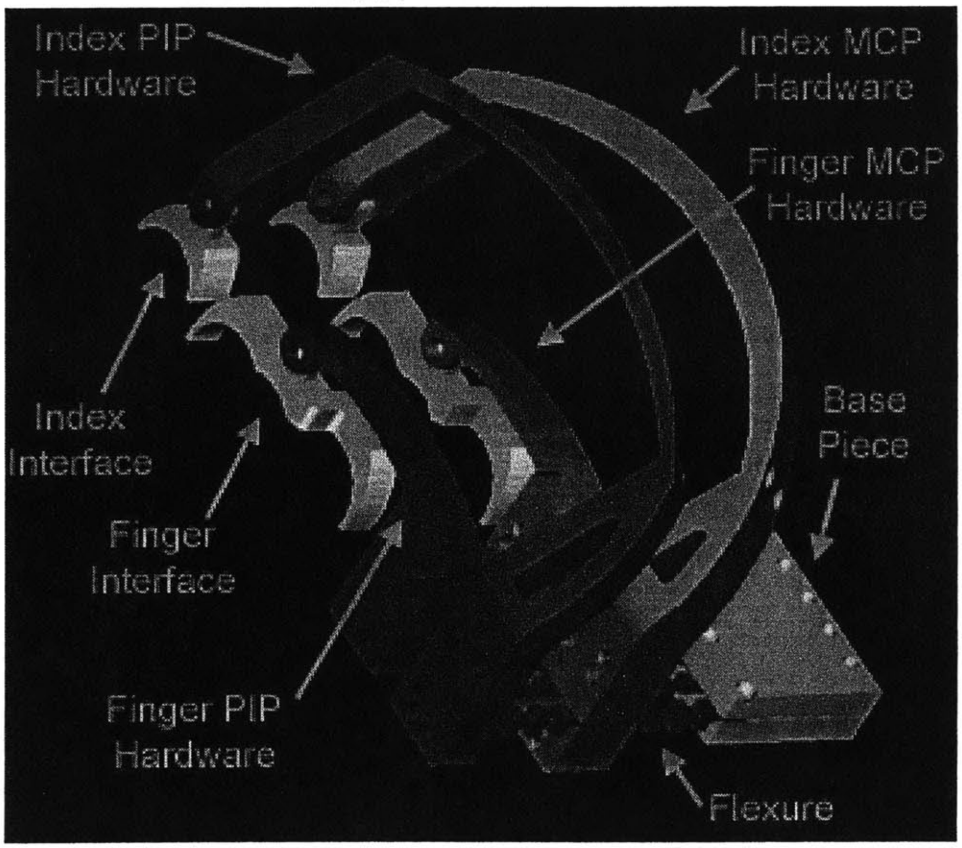


Figure 6-9: Robot Finger Assembly

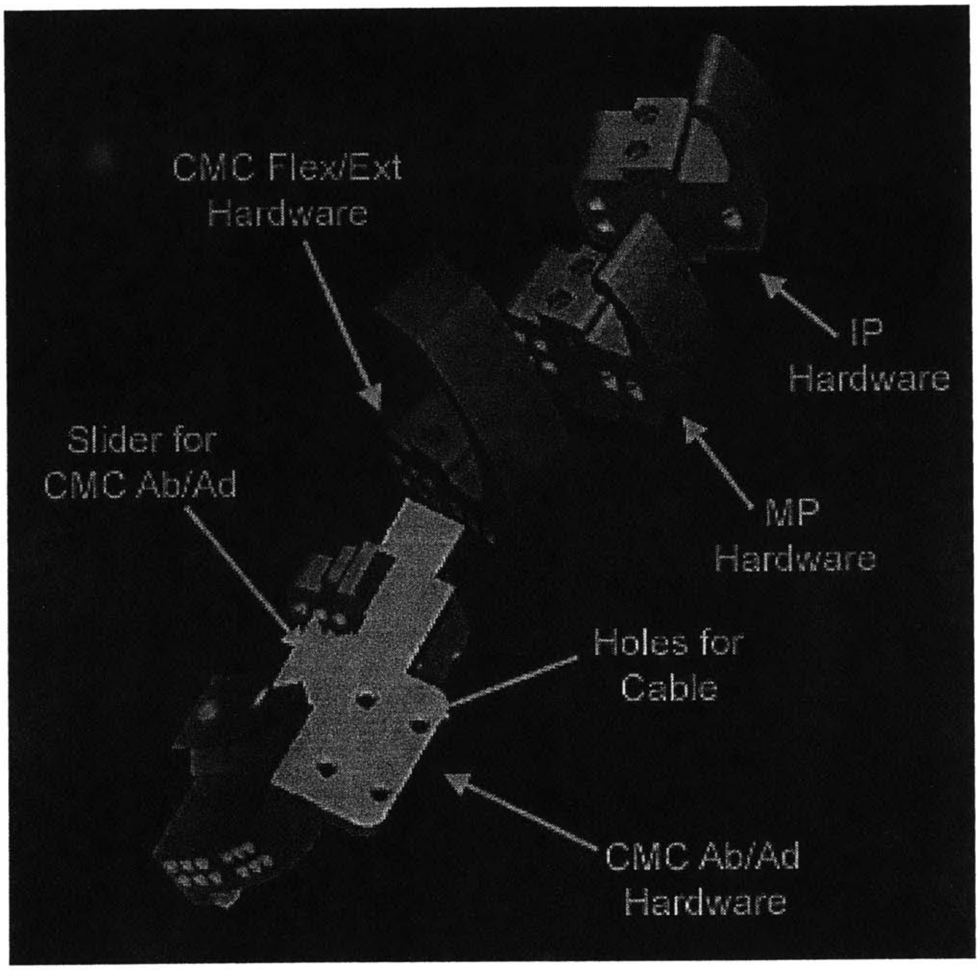


Figure 6-10: Robot Thumb Assembly

IP pieces of hardware will have straps mounted to them to help transmit forces to the patient.

Appendix C contains component specifications, and Appendix D contains part and assembly drawings for all of the components of the final prototype.

Chapter 7

Conclusion

7.1 Current Status

As mentioned in Section 6.3, the hardware for the final prototype is being manufactured and assembled at the time of writing. All of the parts have been designed and all components have been ordered. Many cosmetic details, such as coating the hardware for aesthetic reasons, are being left out since there is much testing that needs to be done before the aesthetics are a concern.

7.2 Design Process

Much of what was learned during the design of the hand robot was in the design process itself. The decision to simplify the degrees of freedom of the robot made the design much more feasible and opened up more options for actuation. As a result, significant time was spent investigating possible methods of actuation. The resulting knowledge about the limitations of hydraulic systems should be considered during future designs. Also, the actual implementation of the cable drive system should be carefully studied to see if improvements on established technology can be made.

The use of prototypes, particularly those manufactured using rapid prototyping technology, provided valuable information about how various design ideas would actually work. It was possible to quickly assess design feasibility and to determine improvements. Earlier and more frequent design reviews might have prevented some of the time spent investigating novel yet somewhat impractical design ideas. Overall, however, the design process was thorough and produced what promises to be a novel robot design.

7.3 Proposed Design Improvements

During the design process, several possible improvements to the design did became apparent. There are two main types of improvements that could be implemented. The first is in the design of the actual hardware. The second is in the materials used or the method of manufacture.

7.3.1 Hardware Improvements

The major change that should be implemented is a very practical one. The original design for the flexure clamps called for 4-40 bolts. When the parts were manufactured it was discovered that the resulting walls surrounding the bolt holes were very thin. Therefore, the clamp bolts should all be changed to 2-56. This change is reflected in the drawings included in Appendix D.

It would also be beneficial to have a version of the wrist cradle which has an integral splint. This would prevent having to somehow attach the cradle to whatever splint is on the patient. Integrating straps into the finger and thumb interfaces would also allow for a smoother looking final product.

Other possible changes to the hardware include creating separate finger and thumb modules. This would allow the therapist to target therapy to specific digits without having to have the patient in the complete robot. In an attempt to provide more general upper extremity therapy, the hand robot alternatively could be implemented in tandem with a variation of the MANUS robot or other active therapy devices.

7.3.2 Material and Manufacture Improvements

As mentioned in Chapter 5, the current prototype hardware is constructed of aluminum. In the final implementation, the finger and thumb interfaces could be manufactured out of a stiff plastic. Plastic molding would allow various colors for aesthetic purposes and in the long run would reduce manufacturing costs. Also, there is a possibility of molding the interfaces and the flexures together, significantly reducing part count. The disadvantage of this is that if the flexure fails, the entire module would have to be replaced. Finally, molding or rapid prototyping the flexures themselves would greatly reduce manufacture time.

7.4 Future Work

Over the next few months, the robot will be assembled and will reach the point where it can be actuated and tested. Once the hardware is assembled it will be connected to a computer for data collection and control. The electronics panel which will contain all of the servoamplifiers and power supplies still needs to be designed and produced. Finally, once all of those aspects are up and working, the robot needs to be characterized.

In order to successfully control the robot, the system needs to be well understood. This will involve trying various controller schemes and obtaining a system frequency response, among other things. Once the robot has been thoroughly characterized and the controller has been proven stable, therapeutic games and a visual interface will be designed and implemented. Finally, the prototype, or an improved version of it, will go out for preliminary clinical testing with stroke patients in a rehabilitation hospital.

Appendix A

Appendix A - Anthropomorphic Data

The first table gives anthropometric data for the individual digits of the hand. The second table is data for the hand itself. All values are in inches. In Table A.1, the total length is defined as the length from the crotch of the finger to the tip, not the total length of the phalanges.

	Biryukova	Tilley
Index Finger		
Length - 1st Phalange	1.792	
Length - 2nd Phalange	1.134	
Length - 3rd Phalange	0.915	
Total Length		3.0 (M) 2.7 (F)
Middle Finger		
Length - 1st Phalange	1.920	
Length - 2nd Phalange	1.308	
Length - 3rd Phalange	0.915	
Total Length		3.4 (M) 3.1 (F)
Ring Finger		
Length - 1st Phalange	1.837	
Length - 2nd Phalange	1.270	
Length - 3rd Phalange	0.915	
Total Length		3.2 (M) 2.9 (F)
Little Finger		
Length - 1st Phalange	1.482	
Length - 2nd Phalange	0.915	
Length - 3rd Phalange	0.877	
Total Length		2.4 (M) 2.2 (F)
Thumb		
Length - 1st Phalange	1.966	
Length - 2nd Phalange	1.308	
Length - 3rd Phalange	1.134	
Total Length		2.3 (M) 2.1 (F)

Table A.1: Digit Anthropometric Data

	NASA	Airforce	Buchholz
Hand			
Breadth (M)	3.44	3.47	3.48
Breadth (F)	2.99		3.22
Length (M)	7.59	7.68	7.42
Length (F)	7.25		6.76
Palm Length (M)	4.3		
Palm Length (F)	3.78		
Wrist Breadth (M)			2.59
Wrist Breadth (F)			2.4

Table A.2: Hand Anthropometric Data

Appendix B

Appendix B - Spreadsheets and Calculations

B.1 Flexure Calculations

Tables B.1 and B.2.

B.2 Motor Calculations

Tables B.3, B.4 and B.5.

Variables		inches	metric
thickness of thin section	t	0.02	5.08e-04
thickness of thick section	h	0.2	5.08e-03
width	w	0.75	1.90e-02
length of thin section	l	0.125	3.17e-03
length of thick section	L	0.125	3.17e-03
number of thin sections			4.00
total length		0.88	2.22e-02
Young's modulus	E		7.00e+07
Poisson's ratio	n		0.4
yield stress			9.40e+07
max allowable angle			1.75e-01
shear modulus	G		2.50e+07
Izz thin section			2.08e-13
Izz thick section			2.08e-10
Ip thin section			2.93e-10
Ip thick section			3.13e-09
Ky per thin section		4.40	770.82
deflection needed	delta		0.002
bending force needed	Fbend	0.35	1.56
max stress in thin section	sigma		8.80e+06
max stress with safety factor of	4		3.52e+07
Kt thin section			2.31
Kt thick section			24.68
Kt total			0.54
max torsion force	Ftorsion	0.02	0.09

Table B.1: Finger Flexure Calculations

Variables		inches	metric
thickness of thin section	t	0.02	5.08e-04
thickness of thick section	h	0.2	5.08e-03
width	w	0.5	1.27e-02
length of thin section	l	0.125	3.17e-03
length of thick section	L	0.125	3.17e-03
number of thin sections			4.00
total length		0.88	2.22e-02
Young's modulus	E		7.00e+07
Poisson's ratio	n		0.4
yield stress			9.40e+07
max allowable angle			1.75e-01
shear modulus	G		2.50e+07
Izz thin section			1.39e-13
Izz thick section			1.39e-10
Ip thin section			8.69e-11
Ip thick section			1.01e-09
Ky per thin section			513.88
deflection needed	delta		0.002
bending force needed	Fbend	0.23	1.04
max stress in thin section	sigma		8.80e+06
max stress with safety factor of	3		2.64e+07
Kt thin section			0.68
Kt thick section			7.92
Kt total			0.16
max torsion force	Ftorsion	0.006	0.028

Table B.2: Thumb Flexure Calculations

	FINGERS		INDEX		THUMB	
	inches	metric	inches	metric	inches	metric
Maximum MCP Force	11.241	50.000	6.745	30.000	10.117	45.000
Maximum PIP Force	5.621	25.000	3.372	15.000	6.745	30.000
Distance to MCP Force	0.627	0.016	0.627	0.016	0.440	0.011
Distance to PIP Force	1.883	0.048	1.883	0.048	1.320	0.034
Maximum MCP Moment	7.054	0.797	4.232	0.478	4.451	0.503
Maximum PIP Moment	10.581	1.195	6.348	0.717	8.903	1.006
Provided MCP Moment	11.479	1.297	8.658	0.978	8.877	1.003
Provided PIP Moment	15.006	1.695	10.774	1.217	13.328	1.506
Distance MCP Flexure to Belt	0.375	0.010	0.375	0.010	0.250	0.006
Distance PIP Flexure to Belt	0.500	0.013	0.500	0.013	0.375	0.010
Necessary MCP Force	30.611	136.160	23.088	102.693	35.508	157.940
Necessary PIP Force	30.012	133.495	21.548	95.845	35.543	158.093
Tension of MCP Belt	45.917	204.240	34.631	154.040	53.262	236.910
Tension of PIP Belt	45.018	200.243	32.322	143.768	53.314	237.140
MCP Inertia (Index)	1.200e-03	1.356e-04	1.200e-03	1.356e-04	4.720e-03	5.333e-04
PIP Inertia (Index)	0.257	1.356e-04	0.257	1.356e-04	2.320e-03	2.621e-04
Acceleration	15.708	15.708	15.708	15.708	15.708	15.708
MCP Necessary Torque	0.019	0.002	0.019	0.002	0.074	0.008
PIP Necessary Torque	4.037	0.456	4.037	0.456	0.036	0.004
MCP Necessary Force	0.050	0.224	0.050	0.224	0.297	1.319
PIP Necessary Force	8.074	35.913	8.074	35.913	0.097	0.432

Table B.3: Flexion/Extension Necessary Force Calculations

	FINGERS		INDEX		THUMB	
	inches	metric	inches	metric	inches	metric
Force to Bend Flexure	0.468	2.080	0.468	2.080	0.187	0.830
Flexure Length	0.880	0.022	0.880	0.022	0.630	0.016
Moment to Bend Flexure	0.206	0.023	0.206	0.023	0.059	0.007
Necessary Provided Force	0.549	2.441	0.549	2.441	0.235	1.046
Coefficient of Friction	0.350	0.350	0.350	0.350	0.350	0.350
Friction Force at MCP	16.071	71.484	12.121	53.914	18.642	82.919
Friction Force at PIP	15.756	70.085	11.313	50.319	18.660	82.999
Total Necessary MCP Force	47.281	210.308	35.807	159.272	54.681	243.224
Total Necessary PIP Force	54.391	241.933	41.483	184.517	54.535	242.571
MCP Pulley Diameter	0.875	0.022	0.875	0.022		
PIP Pulley Diameter	1.000	0.025	1.000	0.025	1.000	0.025
Total Necessary MCP Torque	20.686	2.337	15.666	1.770	27.341	3.089
Total Necessary PIP Torque	27.196	3.073	20.742	2.343	27.267	3.081
Motor Output	3.319	0.375	3.319	0.375	3.319	0.375
Gear Ratio	10.000	10.000	10.000	10.000	10.000	10.000
Estimated Efficiency	0.850	0.850	0.850	0.850	0.850	0.850
Torque to Pulley	28.213	3.188	28.213	3.188	28.213	3.188

Table B.4: Flexion/Extension Motor Torque Calculations

For CMC Abduction/Adduction	inches	metric
Inertia	0.429	0.048
Acceleration	6.981	6.981
Necessary Torque	2.995	0.338
Output Force to Patient	10.117	45.000
Output Torque to Patient	20.234	2.286
Slider Friction Coefficient	0.350	0.350
Friction Force	1.411	6.277
Slider Radius	2.000	0.051
Friction Torque	2.822	0.319
Total Necessary Torque	26.051	2.943
Motor Output	3.319	0.375
Gear Ratio	10.000	10.000
Estimated Efficiency	0.850	0.850
Torque to Slider	28.213	3.188

Table B.5: CMC Abduction/Adduction Motor Torque Calculations

Appendix C

Appendix C - Component List and Specification Sheets

C.1 Component List

C.2 Specification Sheets

Component	Supplier	Model	Price	Quantity
Small Bearing	Motion Industries	Consolidated Bearing FR3ZZ	$7.21 each	16
Large Bearing	Motion Industries	Torrington FS1KDD7	$19.71 each	16
Small Gear	General Product & Gear	Custom	$53.50 each	8
Large Gear	General Product & Gear	Custom	$92.00 each	8
Motor	Kollmorgen	RBE-01213-A02	$898.70 each	8
Servoamplifier	Kollmorgen	CE06200-1R1213A	$980.00 each	8
Servoamp Connectors	Kollmorgen	A-97251	$88.00 each	8
Servoamp Power Supply	Astrodyne	AS-320-24	$169.00 each	2
Encoder	Gurley Precision	R119B-01024Q-5L5-A18SY-03MN	$327.00 each	8
Joint Angle Sensor	Measurand	S720	$375.00 each	7
Sensor Power Supply	Astrodyne	AS-25-5	$39.00 each	1
Cable	Sava Industries	1050SN	$1.17/ft	250
Cable End Fittings	Sava Industries	8062C	$0.47 each	32
Cable Splice Fittings	Sava Industries	7062A	$0.36 each	40
Cable Assemblies	Sava Industries	Custom	$11.70 each	30

Table C.1: Components List

Bearing Model	Bore	OD	Width	Flange Diam	Flange Height
FR3ZZ	0.1250	0.3750	0.156	0.440	0.080
FS1KDD7	0.2500	0.6250	0.196	0.690	0.042

Table C.2: Bearing Specs (all dimensions in inches)

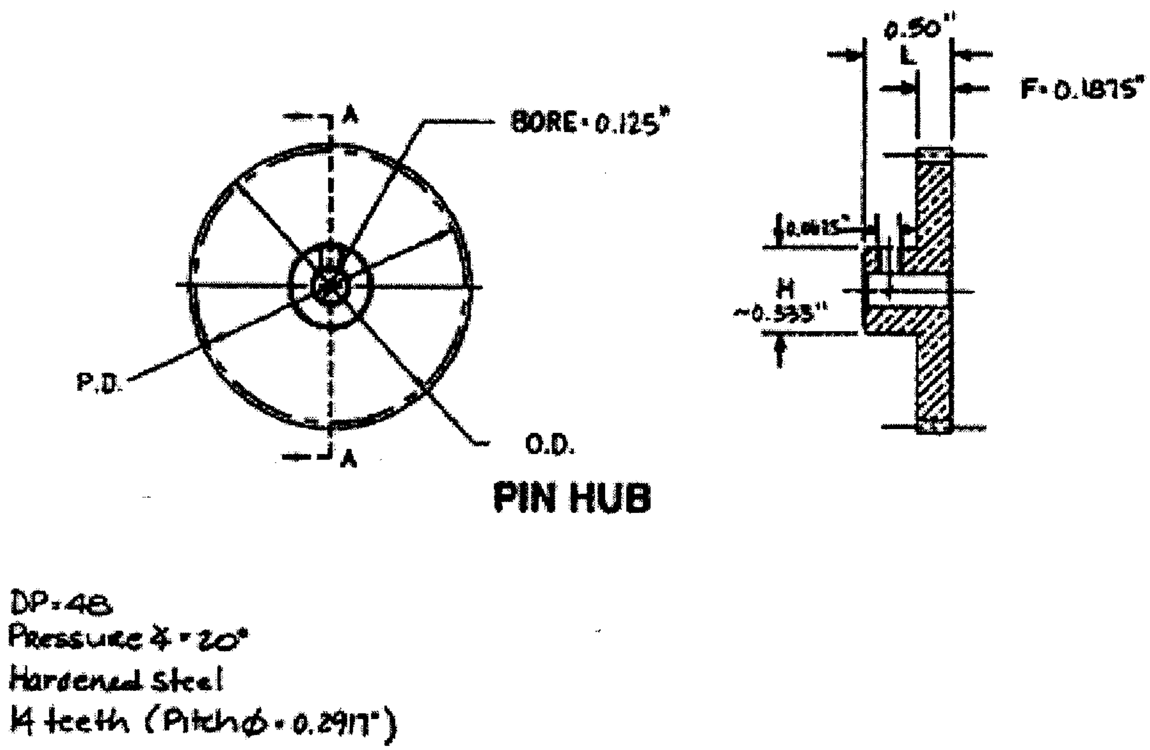


Figure C-1: Small Pinion Gear Drawing

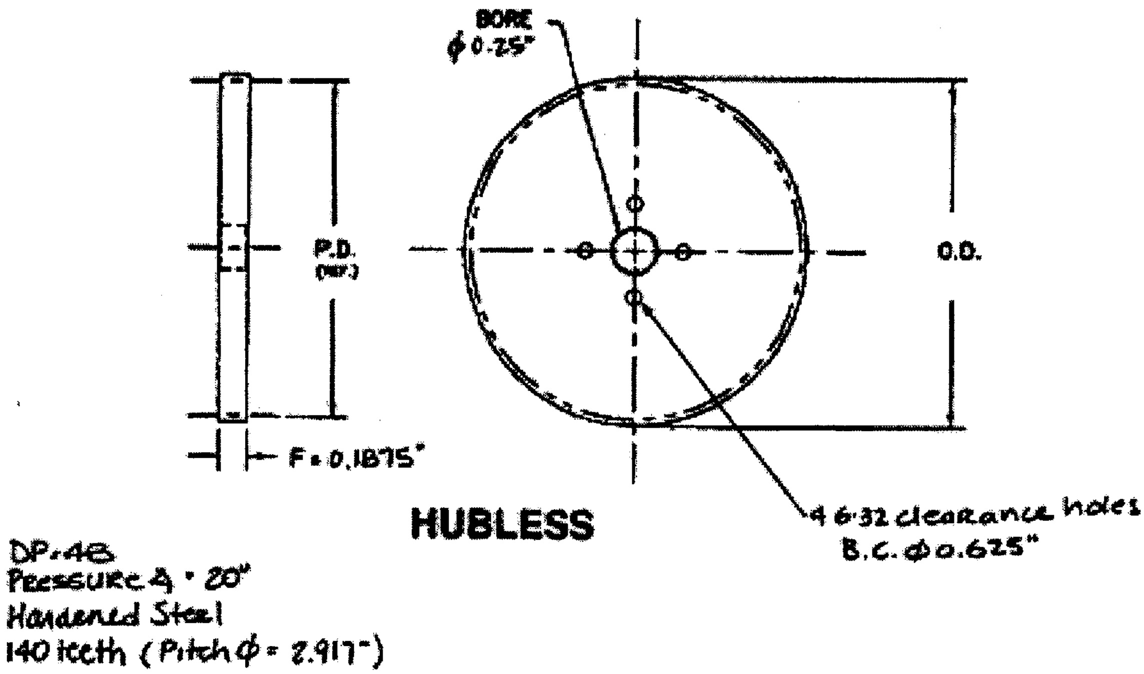


Figure C-2: Large Pinion Gear Drawing

RBE(H) Motor Series

RBE(H) 01210 MOTOR SERIES PERFORMANCE DATA

Motor Parameters		Symbols	Units	01210	01211	01212	01213	01214	01215
Max Cont. Output Power		HP Rated	HP	0.142	0.204	0.243	0.272	0.290	0.310
at 25°C amb.		P Rated	Watts	106	152	181	203	216	231
Speed at Rated Power		N Rated	RPM	13800	9680	8100	7152	6230	5100
Max Mechanical Speed		N Max	RPM	18000	18000	18000	18000	18000	18000
Continuous Stall Torque		Tc	oz-in	16.4	31.6	43.5	54.8	66.2	90.4
at 25°C amb.			N-m	0.115	0.223	0.307	0.387	0.467	0.639
Peak Torque		Tp	oz-in	48.4	114	168	222	282	435
			N-m	0.342	0.806	1.18	1.57	1.99	3.07
Max Torque		Tsl	oz-in	48.4	114	168	222	282	435
for Linear KT			N-m	0.342	0.806	1.18	1.57	1.99	3.07
Motor Constant		Tm	oz-in/$\sqrt{W}$	4.00	7.12	9.50	11.7	13.9	18.4
			N-m/$\sqrt{W}$	0.028	0.050	0.067	0.083	0.098	0.130
Thermal Resistance*		Rth	°C/Watt	4.25	3.86	3.68	3.55	3.44	3.27
Viscous Damping		Fi	oz-in/RPM	1.30E-04	2.96E-04	4.46E-04	5.97E-04	7.78E-04	1.20E-03
			N-m/RPM	9.18E-07	2.09E-06	3.15E-06	4.22E-06	5.49E-06	8.48E-06
Max Static Friction		Tf	oz-in	1.70	2.13	2.53	2.92	3.40	4.50
			N-m	0.0120	0.015	0.018	0.021	0.024	0.032
Max Cogging Torque		Tcog	oz-in	0.41	0.66	0.88	1.10	1.37	2.00
Peak to Peak			N-m	0.0029	0.0046	0.0062	0.0078	0.0097	0.014
Frameless Motor	Inertia	Jmf	oz-in-sec²	7.30E-04	1.20E-03	1.70E-03	2.10E-03	2.70E-03	4.00E-03
			Kg-m²	5.15E-06	8.47E-06	1.20E-05	1.48E-05	1.91E-05	2.82E-05
	Weight	Wtf	oz	4.5	7.2	9.6	12.1	15.1	22.0
			Kg	1.26E-01	2.03E-01	2.74E-01	3.44E-01	4.28E-01	6.24E-01
Housed Motor	Inertia	Jmh	oz-in-sec²	7.60E-04	1.30E-03	1.80E-03	2.20E-03	2.80E-03	4.20E-03
			Kg-m²	5.37E-06	9.18E-06	1.27E-05	1.55E-05	1.98E-05	2.97E-05
	Weight	Wth	oz	11.3	14.2	16.8	19.5	22.6	30.0
			Kg	3.20E-01	4.02E-01	4.77E-01	5.52E-01	6.41E-01	8.50E-01
No. of poles		P		8	8	8	8	8	8

Winding Constants	Symbols	Units	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Current at Cont. Torque	Ic	Amps	5.41	3.89	6.95	5.81	3.63	9.06	5.42	3.38	8.45	5.77	4.00	8.88	6.15	3.73	8.61	5.46	3.31	7.64
Current at Peak Torque	Ip	Amps	15.0	10.6	18.9	20.0	10.6	26.8	20.0	10.6	26.8	22.5	13.4	30.1	25.3	13.4	35.8	25.3	13.4	35.8
Torque Sensitivity	Kt	oz-in/Amp	3.34	4.64	2.60	5.80	9.30	3.72	8.49	13.6	5.45	10.0	14.5	6.50	11.3	18.7	8.08	17.4	28.7	12.4
		N-m/Amp	0.0236	0.0328	0.0183	0.0410	0.0657	0.0263	0.0600	0.0962	0.0385	0.0707	0.102	0.0459	0.0799	0.132	0.0571	0.123	0.203	0.0878
Back EMF constant	Kb	V/KRPM	2.47	3.43	1.92	4.29	6.88	2.75	6.28	10.1	4.03	7.41	10.7	4.81	8.36	13.8	5.97	12.9	21.2	9.19
Motor Resistance	Rm	Ohms	0.698	1.38	0.431	0.664	1.75	0.276	0.803	2.11	0.334	0.733	1.55	0.307	0.666	1.82	0.336	0.890	2.43	0.450
Motor Inductance	Lm	mH	0.280	0.54	0.17	0.32	0.83	0.13	0.44	1.1	0.18	0.47	0.97	0.20	0.48	1.3	0.25	0.71	1.9	0.36

*Rth assumes a housed motor mounted to a 4.0" x 3.75" x 0.25" aluminum heatsink or equivalent

Continuous Duty Capability for 130°C Rise — RBE - 01210 Series

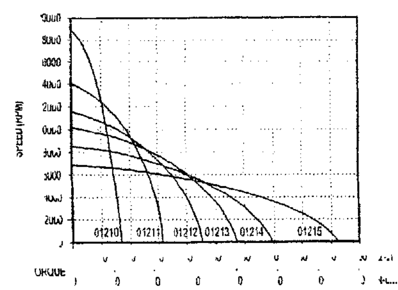
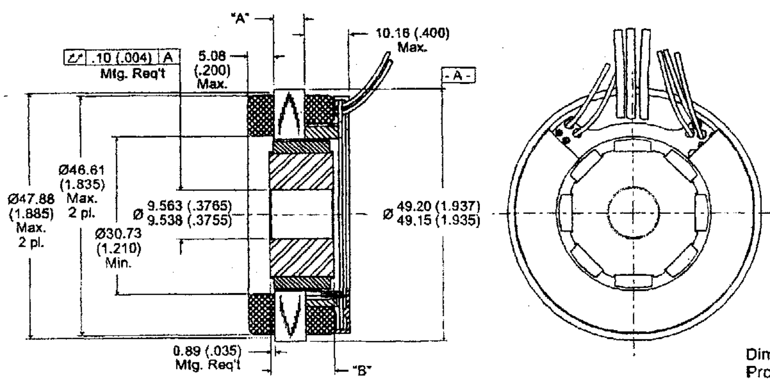


Figure C-3: Motor Spec Sheet 1

DIMENSIONS

RBE-0121X-X00

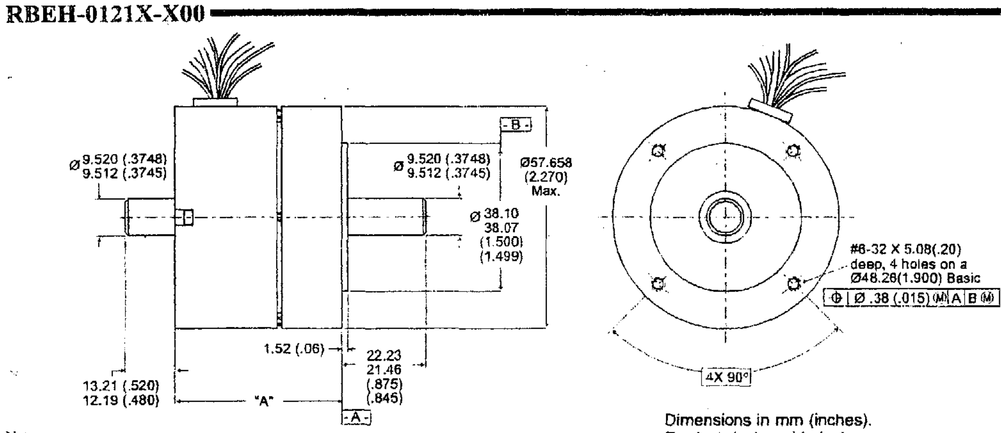


Dimensions in mm (inches).
Product designed in inches.
Metric conversions provided for reference only.

Notes:
1) For a C.W. rotation, as viewed from lead end, energize per excitation sequence table.
2) V-AB, V-BC and V-CA is back EMF of motor phases AB, BC and CA respectively, aligned with sensor output as shown for C.W. rotation only.
3) Mounting surface is between Ø 47.88 (1.885) and Ø 49.17 (1.936) on both sides.

MODEL NUMBER	RBE-01210	RBE-01211	RBE-01212	RBE-01213	RBE-01214	RBE-01215
"A" Dimension	5.72 (0.225)	12.7 (0.500)	19.05 (0.750)	25.4 (1.000)	33.02 (1.300)	50.8 (2.000)
"B" Dimension	12.07 (0.475)	19.05 (0.750)	25.4 (1.000)	31.75 (1.250)	39.37 (1.550)	57.15 (2.250)
Tolerance ± .010 on "A" Dimension.						

RBEH-0121X-X00



Dimensions in mm (inches).
Product designed in inches.
Metric conversions provided for reference only.

Notes:
1) Shaft end play: with a 9 lb reversing load, the axial displacement shall be .013-.15 (.0005-.006).
2) For a C.C.W. rotation, as viewed from pilot end, energize per excitation sequence table.
3) V-AB, V-BC and V-CA is back EMF of motor phases AB, BC and CA respectively, aligned with sensor output as shown for C.C.W. rotation only.

MODEL NUMBER	RBEH-01210	RBEH-01211	RBEH-01212	RBEH-01213	RBEH-01214	RBEH-01215
"A" Dimension	43.05 (1.695)	50.04 (1.970)	56.39 (2.220)	62.74 (2.470)	70.36 (2.770)	88.14 (3.470)

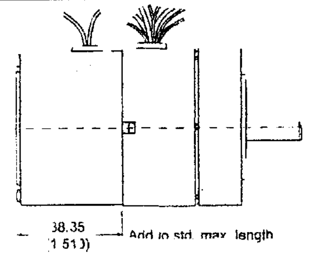
RBE/RBEH LEADWIRE

Motor Leads: #20 AWG Teflon coated per MIL-W-22759/11, 3 leads, 152 (6.00) min lg. ea. 1-black, 1-red, 1-white.

Sensor Leads: #26 AWG type "ET" Teflon coated per MIL-W-16878, 5 leads, 152 (6.00) min lg. ea. 1-blue, 1-brown, 1-green, 1-orange, 1-yellow.

Figure C-4: Motor Spec Sheet 2

OPTIONS — RBEH-0121X



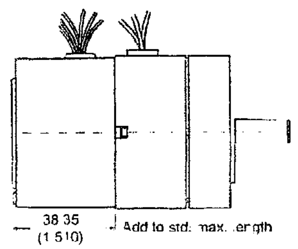
Dimensions in mm (inches).
Product designed in inches.
Metric conversions provided for reference only.

BRAKE OPTION

An integral electromagnetic fail-safe brake can be added to the rear of the motor. Operating in the POWER OFF/BRAKE ON mode, the brake provides 48 oz-in of torque for static parking and emergency braking. To release the brake, 24 VDC and 0.13 Amps max need to be applied.

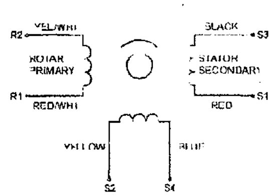
-Fail-safe brake
-48 oz-in holding torque
-Release voltage of 24 VDC (0.13 Amps)

RESOLVER OPTION



Dimensions in mm (inches).
Product designed in inches.
Metric conversions provided for reference only.

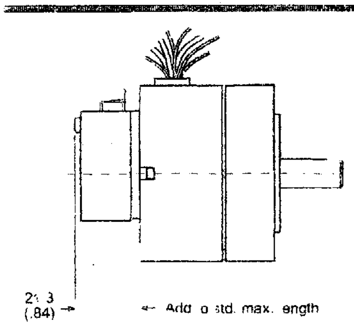
A frameless resolver is available to provide position feedback computable with a wide variety of CNC and other position loop controllers. This option is required for commutation when using SERVOSTAR or other resolver based controller.



NORMAL CHARACTERISTICS AT 25°C

PRIMARY	ROTOR
INPUT VOLTAGE	4.25V, 7 kHz
INPUT CURRENT	55 MA. MAX.
INPUT POWER	0.12 WATTS
TRANSFORMATION RATIO (± 5%)	0.470
PHASE SHIFT	4° LEADING ± 3°
IMPEDANCES (± 15%)	
Z_{RO}	48 + j70
Z_{SO}	62 + j80
Z_{SS}	53 + j63
Z_{RS}	42 + j55
D.C. RESISTANCE (± 10%)	
STATOR	33 Ohm
ROTOR	16 Ohm
NULL VOLTAGE	20 MV. MAX.
ELECTRICAL ERROR	± 7 MINUTES MAX.
OUTPUT VOLTAGE	2.0 V ± 5%
OPERATING TEMPERATURE	-55° TO +155°C

ENCODER OPTION



Dimensions in mm (inches).
Product designed in inches.
Metric conversions provided for reference only.

An incremental encoder is available having TTL quadrature and marker pulse outputs. 200 to 2048 lines are available. The standard is 1024 lines with the marker pulse.

Parameter	Min	Max	Units
Temperature	-40	100	°C
Supply Voltage	4.5	5.5	Volts
Supply Current	30	85	mA
Count Frequency		100	kHz
Velocity		10K	RPM

Resolution Cycles/Rev.
200
500*
1000
1024
2000*
2048*

Index option not yet available for resolutions marked by *

Figure C-5: Motor Spec Sheet 3

RBE(H) Motor Series

ORDERING INFORMATION

RBE(H) B - 012 12 - A 00

TYPE
RB - Frameless Brushless Motor
RBE - Frameless Brushless Motor with Hall Sensors
RBEH - Housed Brushless Motor with Hall Sensors

OPTIONS
B - Fail-Safe Brake
E- - Encoder
R - Resolver (Drop 1st E)

Motor frame
004, 005, 007, 012, 015, 018, 021, 030, 045, 062

Stack Length
10, 11, 12, etc.

Winding
A, B, C, etc.

Mechanical Deviations
00 - Standard

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Figure C-6: Motor Spec Sheet 4

SERVOSTAR CD

AMPLIFIER SPECIFICATIONS

Electrical characteristics
- Closed loop velocity bandwidth up to 400 Hz
- Motor current ripple frequency (32 kHz)
- Long term speed regulation (0.01%)
- Position loop update rate 500 µs (2 kHz)
- Velocity loop update rate 250 µs (4 kHz)
- Commutation update rate 62.5 µs (16 kHz)
- Current loop update rate 62.5 µs (16 kHz)

Fault protection
- Output phase to phase short circuit protection
- Overvoltage
- Undervoltage
- Overtemperature (motor and amplifier)
- Overspeed
- Overcurrent
- Feedback loss
- Foldback
- Supply loss
- Excessive position error

Environmental
- Operation range
  - Ambient 0 to 45°C (derated above ambient)
  - Storage -20°C to 70°C
- Humidity (non-condensing) 10% to 90%

Velocity Loop Compensation
- Vel: PI, PDFF or Pole Placement selectable algorithms
- Factory preset or field tunable
- MOTIONLINK® software provides tuning programming via RS-232 or RS-485 serial interface
- Adjustable filters

Position Loop Compensation
- PID

Inputs
- Analog command: ±10V
  Resolver feedback models: 14 bit resolution provides up to 16,000 to 1 dynamic speed range
  Encoder feedback models: 15 bit resolution provides up to 32,000 to 1 dynamic speed range
- Remote enable: 24V
- Three multi-purpose 24V inputs Configurable to: CW limit switch, CCW limit switch, gear enable, start motion, second current limit, change velocity to torque mode, home switch, search for home, move to home registration capture, active disable, control fault relay, hold position plus using two inputs, up to four stored indexes or speeds can be executed
- Pulse command: up/down, pulse/direction, pulse or quadrature encoder format into RS-485 receivers or opto isolators

Communications
- RS-232 or RS-485 serial interface 9600 or 19.2 kb

Outputs
- Fault: contact closure rated for 1 Amp, 24 Volt
- One multi-purpose 24V output configurable to: speed exceeded, current exceeded, amplifier in foldback, brake enable, motion complete, in position, zero speed detect

Operational modes
- Torque control — from analog or serial command
- Velocity control — from analog or serial command
- Pulse following / Up-Down count
- Gearing from quad encoder input
- Position control

Diagnostics
- Seven segment LED display
- Error history log
- Internal variable monitoring
- PC scope

Motor Feedback
- Resolver: sine/cosine 2V peak to peak (SERVOSTAR CD provides 4.25V peak to peak for resolver excitation)
- Encoder: 5V quadrature with or without Halls, with or without marker, up to 3 MHz before quadrature (12 MHz after quadrature)

Amplifier Ratings

Model	Output Continuous Current Per Phase (RMS/phase)	Output Peak Current Per Phase (1/2 sec)	Rated Output Continuous Power (kW)	Internal Power Dissipation (Watts)	PWM Switching Frequency (kHz)	AC Input Line Voltage (1 phase)	Rated Input Power	Regen. Option
Cx03	3	9	1.1	37	16	115-230	1.7	ERH-26
Cx06	6	18	2.2	84	16	115-230	2.8	ERH-26

10 KOLLMORGEN • Radford, Virginia • 1-800-77 SERVO

Figure C-7: Servoamplifier Spec Sheet 1

RESISTIVE REGENERATION SIZING/DIMENSIONS

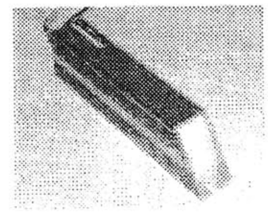
Resistive Regeneration Sizing

Shunt regeneration is required to dissipate energy that is pumped back into the DC bus during load deceleration. The amount of shunt regeneration required is a function of the sum of simultaneously decelerating loads. The loads need to be defined in terms of system inertia, maximum speed, and deceleration time. In addition, the duty cycle must be known. Application Note A-SU-001-H details a calculation method to determine proper regeneration sizing.

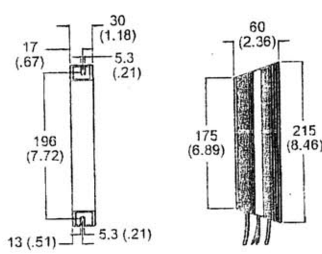
Transformer Sizing (Required only for voltage matching)

The SERVOSTAR CD can be connected to a line. Built-in soft-start circuitry protects power supply components and eliminates nuisance tripping of breakers or fuse blowing due to large in-rush currents. Transformers are only required for voltage matching purposes. In this case, the transformer should have a 115 or 230 VAC secondary depending on the operating voltage. The kVA rating of the transformer should take into account not only the servo output load requirements but also losses in the system and power factor. For single phase operated systems such as these, the transformer KVA ratings should be two times the CD amplifier output power rating.

Model	Transformer KVA rating
Cx03	2.2
Cx06	4.4



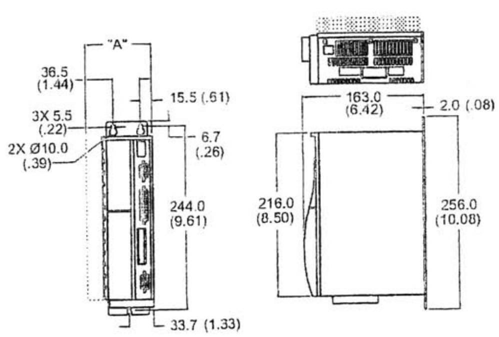
Model	Watts	Ohms
ERH-26	200	20



Resistive Regen ERH-26

SERVOSTAR CD DIMENSIONS

Cx03/06



	DIM. "A"
3 AMP	67.4 (2.65)
6 AMP	88.4 (3.48)

Dimensions in mm (inches)

Figure C-8: Servoamplifier Spec Sheet 2

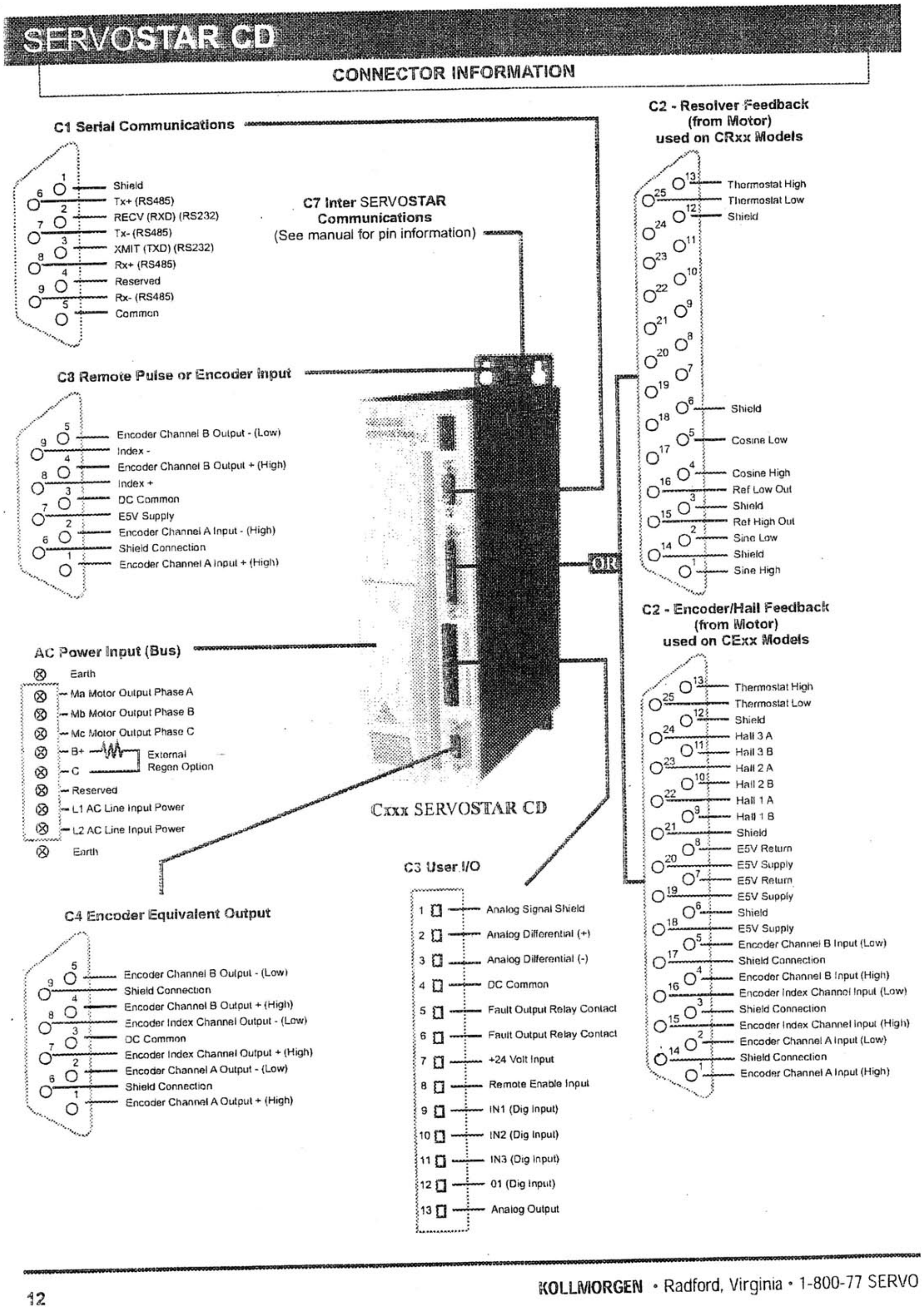


Figure C-9: Servoamplifier Spec Sheet 3

SERVOSTAR CD

SYSTEM ORDERING INFORMATION

C R 06 200 -2 G 402 B

SERVOSTAR Family
C - **SERVOSTAR CD** Compact Drive

Feedback
R - Resolver
E - Encoder

Current Rating (Cont. A/Ø)
(Compact Drive: 03,06 Amp ratings only)

Model
200 - Standard model

Voltage Level
0 - No Comp
2 - Standard
Y - Special Compensation three digit extension follows the Y designator

Motor Model
0 - No Comp
G - **GOLDLINE** (B, BE, M, ME, MT, EB)
R - RBE
H - **SILVERLINE** (H)

Motor Frame and Stack
000 - No Comp

Winding
0 - No Comp

Figure C-10: Servoamplifier Spec Sheet 4

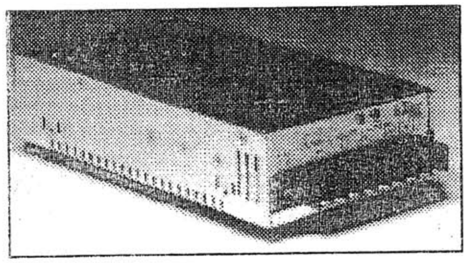
ASTRODYNE

Enclosed Switching 300 Watt Power Supplies

AS-320 Series

- 115/230 VAC Sw. Sel. Input
- High Efficiency
- Regulated Outputs
- 3000V Isolation
- Built in EMI Filter

c UL US



Unit measures 4.6"W x 8.6"L x 2"H

MODEL SELECTIONS

Model Number	Output Voltage	Output Amps (MAX)	Price 1	Price 25	
SINGLE OUTPUT					
AS-320-5	5 VDC	50	$169	$163	Contact Factory for High Volume Pricing
AS-320-7.5	7.5 VDC	36	$169	$163	
AS-320-12	12 VDC	25	$169	$163	
AS-320-13.5	13.5 VDC	22	$169	$163	
AS-320-15	15 VDC	20	$169	$163	
AS-320-24	24 VDC	12.5	$169	$163	
AS-320-27	27 VDC	11	$169	$163	
AS-320-48	48 VDC	6.5	$169	$163	

300 Myles Standish Blvd., Taunton, MA 02780
Ph: 1-800-823-8082 Fax: 508-823-8181

Figure C-11: Servoamplifier Power Supply Spec Sheet 1

ASTRODYNE

Enclosed Switching 300 Watt Power Supplies

All specifications are typical at nominal input, full load, and 25DegC unless otherwise noted

INPUT SPECIFICATIONS

Input Voltage Range	88-132 / 176-264 VAC Switch Selected
Frequency Range	47-440 Hz
Inrush Current, typ:	20A/115VAC, 40A/230VAC *

OUTPUT SPECIFICATIONS

Voltage and Current	See Selection Chart
Load Regulation (0% to 100% Load)	5 & 7.5V: +/- 1%, typ All Others: +/- 0.5%, typ
Line Regulation	+/- 0.5%, typ
Voltage Tolerance	5 & 7.5V: +/-2%, typ All Others: +/-1%
DC Voltage Adjust (typ)	+/-10%, typ
Temperature Coefficient	+/-0.03%/DegC
Ripple/Noise	5 thru 24V: 150mV, typ 27V: 200mV, typ 48V: 240mV, typ
Over Voltage Protection	Clamp, 115-135%, typ *
Short Circuit Protection	Continuous, self-recovering
Setup, Rise, Hold Up Time	2S, 20mS, 20mS

GENERAL SPECIFICATIONS

Input-Out Isolation	I/P-O/P: 3000VAC I/P-Ground: 1500VAC
Efficiency	83%, typ
Switching Frequency	167Khz, (fixed, typical)
Approvals	UL
Safety	
UL1950	UL File # E183223

ENVIRONMENTAL SPECIFICATIONS

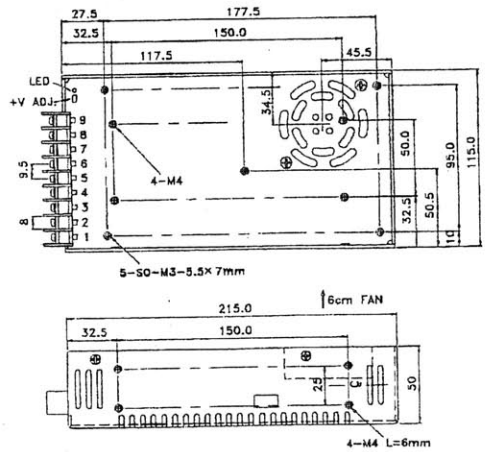
Oper. Temperature	-10 to +60 DegC(See Derate)
Storage Temperature	-20 to +85 DegC *
Relative Humidity	20% to +90%, non-cond *
MTBF	403 kHrs Mil Std 217, 25C

PHYSICAL SPECIFICATIONS

Size	4.6" x 8.6" x 2.0"
Construction	Enclosed
Weight	2.53 lb, (1.15Kg)

* These are stress ratings. Exposure of the devices to any of these conditions may adversely affect long term reliability. Proper operation under conditions other than the standard operating conditions is neither warranteed nor implied.

MECHANICAL DIMENSIONS



Pin #	Outputs
1	AC Line
2	AC Neutral
3	FG
4	- Output
5	- Output
6	- Output
7	+ Output
8	+ Output
9	+ Output

OUTPUT DERATING CURVE

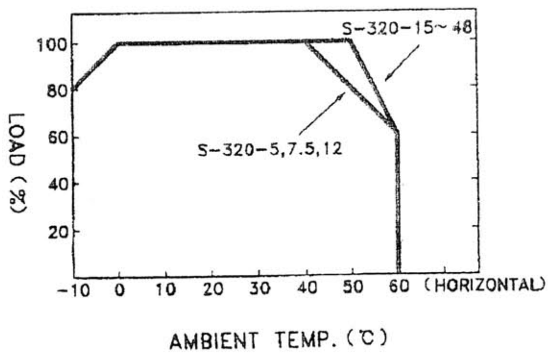


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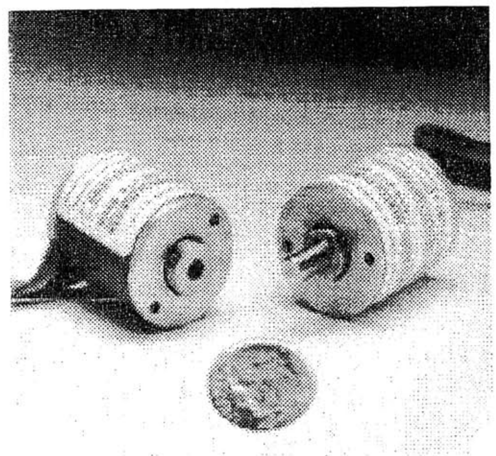
Figure C-12: Servoamplifier Power Supply Spec Sheet 2

GPI Gurley Precision Instruments

ISO 9001 Certified

Motion type:	Rotary
Usage Grade:	Light industrial
Output:	Incremental
Max. Resolution:	40,960 counts/rev



Model R119 Rotary Incremental Mini-Encoder

SMALLEST HIGH RESOLUTION ENCODER!

The Model **R119** optical incremental encoder is designed for light industrial applications that require high resolution in a very small package. It is available in both shafted and blind hollow shaft versions. The two models share these features:

- ϕ19 mm body
- LED illumination for long life (>100,000 hours)
- Differential photo-detectors for signal stability
- Single-board, surface-mount electronics for reliability
- RS-422 differential line driver output for noise immunity
- Zero index signal
- Monolithic integrated ASIC for internally interpolated resolutions up to 10,240 cycles/rev (40,960 counts/rev)

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http://www.gurley.com encoders@gurley.com

Figure C-13: Encoder Spec Sheet 1

SPECIFICATIONS

	See Note	Model **R119B** or Model **R119S**
Maximum line count on disc		1024
Maximum cycles/rev (quad sq waves)		10,240
Max counts/rev (after quad decode)		40,960
Internal square wave interpolation		1X, 2X, 5X or 10X
Instrument error, ± arcminutes	1, 2	4
Quadrature error, ± electrical degrees	1, 3	24
Interpolation error, ± quanta	1, 4	0.15
Maximum output frequency, kHz		
1X square waves		100
2X square waves		150
5X square waves		300
10X square waves		500
Starting torque, in-oz (N-m) @20°C		0.07 (4.9×10^{-4})
Running torque, in-oz (N-m) @20°C		0.04 (2.9×10^{-4})
Moment of inertia, in-oz-s^2 (g-cm^2)		3.4×10^{-6} (0.24)
Maximum weight, oz (g)		0.5 (15)
Sealing		IP50
Operating temperature, °F (°C)		32 to 158 (0 to 70)
Storage temperature, °F (°C)		0 to 160 (-18 to 71)
Humidity, % rh, non-condensing		98
Shock		31 g (300 m/s^2)
Vibration		10 g (100 m/s^2)

S = Shaft version; **B** = Blind hollow shaft version

NOTES:

1. Total Optical Encoder Error is the algebraic sum of *Instrument Error* + *Quadrature Error* + *Interpolation Error*. Typically, these error sources sum to a value less than the theoretical maximum. Error is defined at the signal transitions and therefore does not include quantization error, which is ±1/2 quantum. ("Quantum" is the final resolution of the encoder, after user's 4X quadrature decode.) Accuracy is guaranteed at 20°C.
2. *Instrument Error* is the sum of disc pattern errors, disc eccentricity, bearing runout and other mechanical imperfections within the encoder. This error tends to vary slowly around a revolution.
3. *Quadrature Error* is the combined effect of phasing and duty cycle tolerances and other variables in the basic analog signals. This error applies to data taken at all four transitions within a cycle; if data are extracted from 1X square waves on a 1X basis (i.e., at only one transition per cycle), this error can be ignored.

   Error in arcminutes = (60) x (error in electrical degrees) ÷ (disc line count)
4. *Interpolation Error* is present only when the resolution has been electronically increased to more than four data points per optical cycle. It is the sum of all the tolerances in the electronic interpolation circuitry.

   Error in arcminutes = (21600) x (error in quanta) ÷ (counts/rev)

As part of our continuing product improvement program, all specifications are subject to change without notice.

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http://www.gurley.com **encoders@gurley.com**

Figure C-14: Encoder Spec Sheet 2

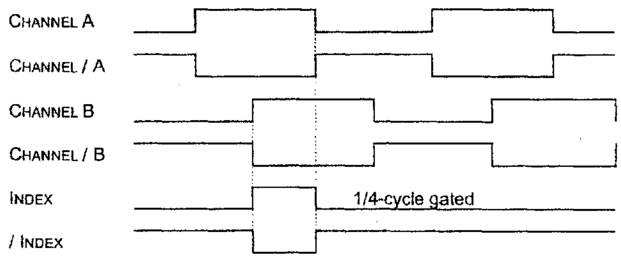
INPUT POWER

+5 VDC @100 mA max.

SQUARE WAVE OUTPUT

Quadrature square waves at 1, 2, 5 or 10 times the line count on the disc. On all channels: EIA/RS-422 balanced differential line driver, protected to survive an extended-duration short circuit across its output. May be used single-ended for TTL-compatible inputs. Index is ¼-cycle wide, gated with the high states of channels A and B.

OUTPUT WAVEFORMS (CW rotation shown)



ELECTRICAL CONNECTIONS

Output Functions	Wire Colors Conn. Code **P**	Pos. No. Conn. Code **Y**
A	Orange	2
/ A	Yellow	3
B	Violet	6
/ A	Gray	7
IND	Green	4
/ IND	Blue	5
+V	Red	1
COMMON	White	8

NOTE: Channel A leads Channel B for clockwise shaft rotation, viewed from the shaft end.

FLEXIBLE SHAFT COUPLING

R119B Tether Mount	
Maximum parallel offset, in (mm)	0.002 (0.05)
Maximum angular misalignment, degrees	2.0
Maximum axial extension or compression, in (mm)	0.008 (0.2)

NOTE: Flexible couplings are intended to absorb normal installation misalignments and run-outs in order to prevent undue loading of the encoder bearings. To realize all the accuracy inherent in the encoder, the user should minimize misalignments as much as possible.

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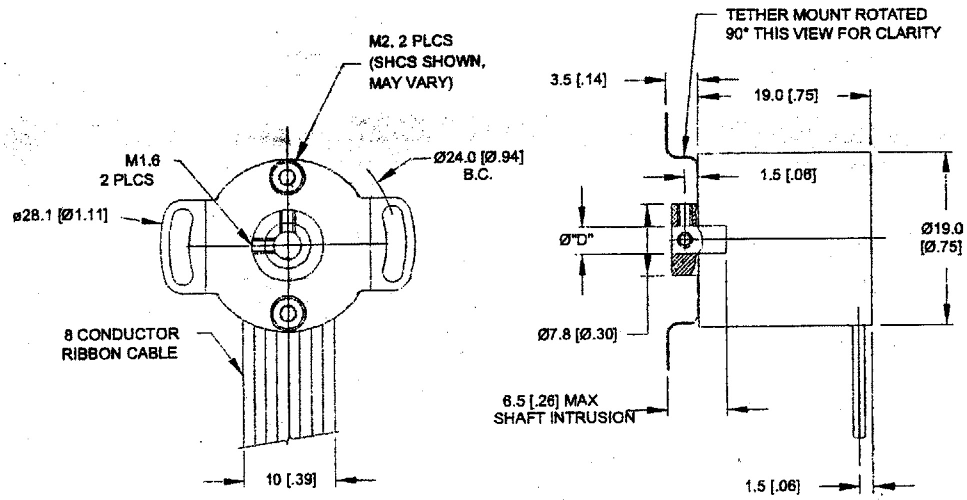
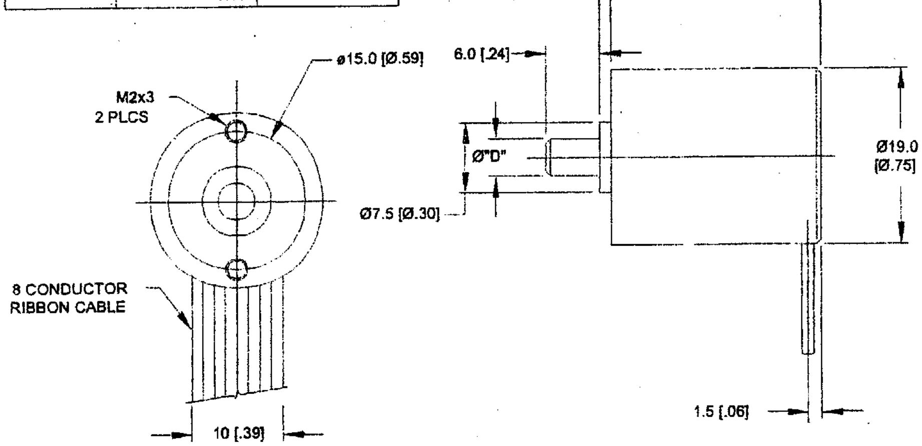
Figure C-15: Encoder Spec Sheet 3



R119B (BASE CODE A)

"D" TABLE		
"DIA" CODE	R119S "D"	R119B "D"
04M	4mm h6	N/A
03M	3mm h6	3mm H7
02E	0.125" +.0000 -.0003	0.125" +.0005 -.0000



R119S (BASE CODE B)

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http://www.gurley.com encoders@gurley.com

Figure C-16: Encoder Spec Sheet 4

ORDERING INFORMATION

R119 SHAFT - LINES Q - 5 L INTERP - BASE CAB S CONN – DIA SF

SHAFT
- **S** Shaft version
- **B** Blind hollow shaft

LINES - Disc line count
00360, **00500**, 00512, 00900, 01000, **01024**
Bold counts exist; others will be added.
Consult factory for other line counts

INTERP - Interpolation factor
01, 02, 05, 10

BASE
- **A** Use with **R119B**
- **B** Use with **R119S**

CAB - Cable length, inches
- **18** Standard

CONN - Connector
- **P** Pigtails (no connector)
- **Y** 8-pos ribbon cable socket connector (Berg 71602-308 or equal)

DIA - Shaft diameter
- **04M** 4 mm (SHAFT = **S**)
- **03M** 3 mm (SHAFT = **S** or **B**)
- **02E** 1/8" (SHAFT = **S** or **B**)

SF - Special features
- **#** Issued at time of order to cover special customer requirements
- **N** No special features

SPECIAL CAPABILITIES

For special situations, we can optimize catalog encoders to provide higher frequency response, greater accuracy, wider temperature range, reduced torque, non-standard line counts, or other modified parameters. In addition, we regularly design and manufacture custom encoders for user-specific requirements. These range from high-volume, low-cost, limited-performance commercial applications to encoders for military, aerospace and similar high-performance, high-reliability conditions. We would welcome the opportunity to help you with your encoder needs.

WARRANTY

Gurley Precision Instruments offers a limited warranty against defects in material and workmanship for a period of one year from the date of shipment.

R119 data sheet.doc
5-Jul-00

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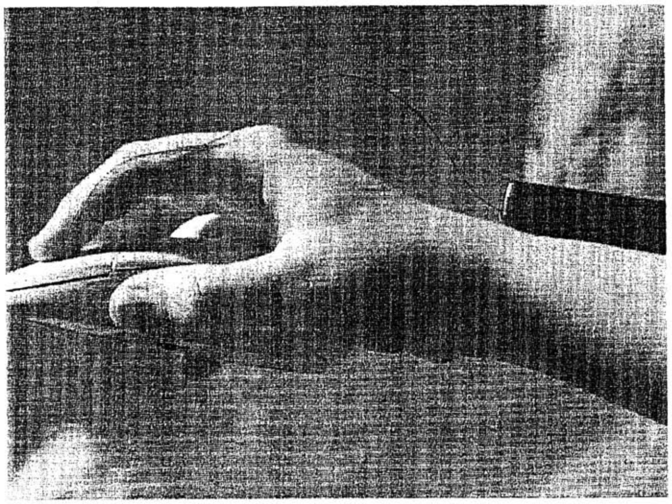
http://www.gurley.com encoders@gurley.com

Figure C-17: Encoder Spec Sheet 5

S720 MINIATURE JOINT ANGLE SHAPE SENSOR™

Revision 000613



The S720 SHAPE SENSOR™ is a comfortable, flexible, bipolar joint angle sensor. Can be used to measure the angle of any small 1 degree of freedom joint including fingers, toes, or mechanical parts. Because of its small size, the S720 can be mounted with a reusable, flexible adhesive polymer, which allows easy adjustment to a natural form along the neutral axis of the joint. The polymer may be used either directly on the skin, on a glove or on biocompatible tape.

Stand Alone: Apply your own regulated power supply, 5 to 15 volts. The output is a high level signal, ratiometric with the supply voltage, that requires no additional signal conditioning. This sensor is ready to make measurements right out of the box.

As a Package: A package includes the S720 and an S270 12 bit data acquisition system. The S270 comes complete with a two channel 12 bit A/D and Windows software allowing the display and storage of sensor data. Power for up to two sensors is supplied by the A/D.

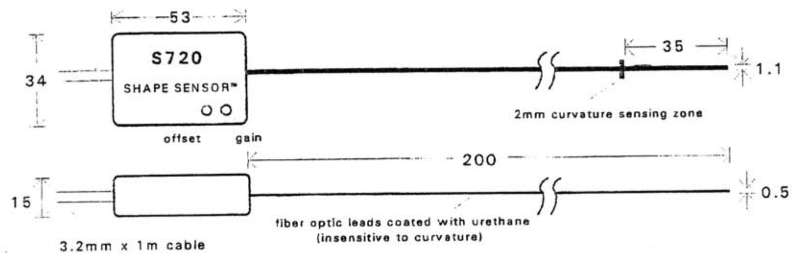
Options: The S720 SHAPE SENSOR™ can be made longer to extend the distance from the electronics to the sensor for measurements in magnetic-sensitive and explosive environments. It can also be hermetically sealed to operate in harsh environments.

Larger Joints: For larger one degree of freedom joints you can use our S700 or S710 Joint Angle SHAPE SENSOR™.

Multiple Joints: For multiple joints or joints with multiple degrees of freedom try our SHAPE TAPE™ "the tape that knows where it is."

Measurand Inc.

Figure C-18: Joint Angle Sensor Spec Sheet 1



(dimensions in millimeters unless otherwise indicated)

CHARACTERISTICS

These typical characteristics are approximate and subject to change without notice
g = gram; gf = gramforce = 9.8 mN; G = acceleration of gravity.
Characteristics are for 5 VDC supply.

Full scale (FS) range: ±1.0 V for ±90° joint angles.

Output voltage for straight sensor: 2.5 V, ± 0.2 V.

Accuracy: ±2% of FS.

Resolution: 0.05°.

Noise floor: 0.07 mVrms/Hz$^{1/2}$.

3dB Bandwidth: 1.0 kHz.

Environmental: -40°C to +70°C.

Temperature sensitivity, offset: ±2% of FS, -40°C to +70 °C.

Excitation: 5 to 15 VDC (Supply current at 5 VDC, 15°C: ≤ 5 mA).

Electrical Connections: Red: Power Supply (5 to 15 volts regulated); Black: Ground(Power Supply and Signal); Clear: Sensor Output.

Measurand Inc.
921 College Hill Road
Fredericton, NB Canada E3B 6Z9
Tel: 506-462-9119; Fax 506-462-9095
Email: sales@measurand.com
www.measurand.com

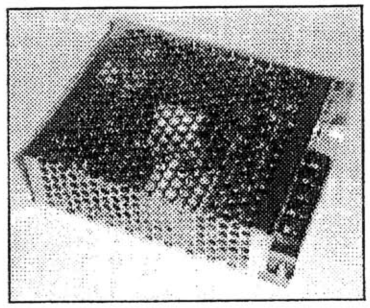
Figure C-19: Joint Angle Sensor Spec Sheet 2

ASTRODYNE

Enclosed Switching
25 Watt Power Supplies

AS-25 Series

- Universal 85-265VAC Input
- High Efficiency
- Regulated Outputs
- 3000V Isolation
- Built in EMI Filter



Unit measures 3.88"W x 3.96"L x 1.4"H

MODEL SELECTIONS

Model Number	Output Voltage	Output Amps (MAX)	Price 1	Price 25
SINGLE OUTPUT				
AS-25-5	5 VDC	5	$39	$35
AS-25-12	12 VDC	2.1	$39	$35
AS-25-15	15 VDC	1.7	$39	$35
AS-25-24	24 VDC	1.1	$39	$35

Contact Factory for High Volume Pricing

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Figure C-20: Sensor Power Supply Spec Sheet 1

ASTRODYNE

All specifications are typical at nominal input, full load, and 25DegC unless otherwise noted

Enclosed Switching 25 Watt Power Supplies

INPUT SPECIFICATIONS

Input Voltage Range	85-264 VAC
Frequency Range	47-440 Hz
Inrush Current, typ:	15A @ 115VAC Input *
	30A @ 230VAC Input *

OUTPUT SPECIFICATIONS

Voltage and Current	See Selection Chart
Load Regulation	5V: +/- 1% of FS, typ
(0% to 100% Load)	All Others: +/- 0.5%, typ
Line Regulation	+/- 0.5, typ
Voltage Tolerance	5V: +/-2%, typ
	All Others: +/-1%
DC Voltage Adjust (typ)	5V: +10%, -5% of FS
	All Others: +/-10%
Temperature Coefficient	+/-0.03%/DegC
Ripple/Noise	5V: 50mV Pk-Pk, typ
	All Others: 100mV Pk-Pk, typ
Over Voltage Protection	Clamp, 115-135% *
Short Circuit Protection	Continuous, self-recovering
Setup, Rise, Hold Up Time	800mS, 50mS, 10mS /115VAC
	300mS, 50mS, 80mS /230VAC

GENERAL SPECIFICATIONS

Input-Out Isolation	I/P-O/P: 3000VAC
	I/P-Ground: 1500VAC
Efficiency	76%, typ
Switching Frequency	56Khz, (fixed, typical)
Approvals	UL / TUV / CE
Safety	

EN60950, IEC950, TUV File # R9653551
UL1012, UL File # E127738

ENVIRONMENTAL SPECIFICATIONS

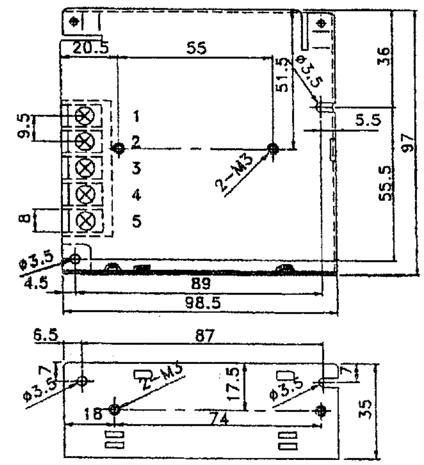
Oper. Temperature	-10 to +60 DegC(See Derate)
Storage Temperature	-20 to +85 DegC *
Relative Humidity	10% to +95%, non-cond *
EMC	CISPR22 (EN55022)
	IEC801-2,3,4
MTBF	26 kHrs
	Mil Std 217, 25C

PHYSICAL SPECIFICATIONS

Size	3.88" x 3.96" x 1.4"
Construction	Enclosed
Weight	0.8 oz, (370g)

* These are stress ratings. Exposure of the devices to any of these conditions may adversely affect long term reliability. Proper operation under conditions other than the standard operating conditions is neither warranted nor implied.

MECHANICAL DIMENSIONS



Pin #	Outputs
1	- Output
2	+ Output
3	FG
4	AC Neutral
5	AC Line

OUTPUT DERATING CURVE

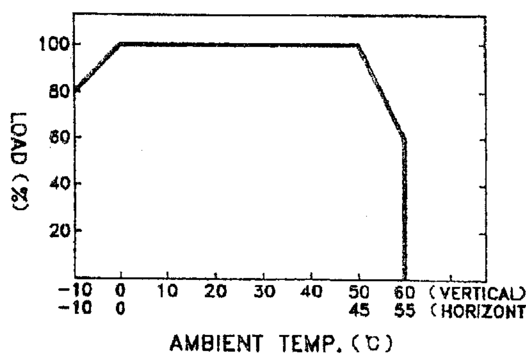


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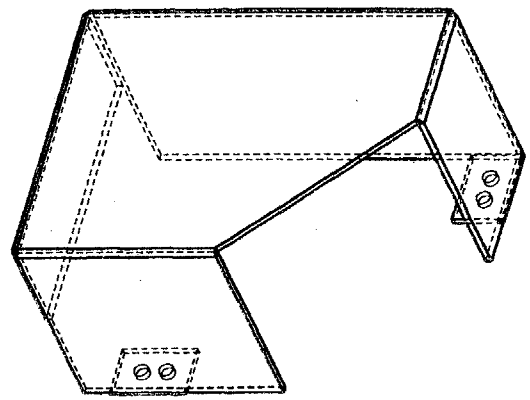
Figure C-21: Sensor Power Supply Spec Sheet 2

Appendix D

Appendix D - Pro/Engineer Drawings

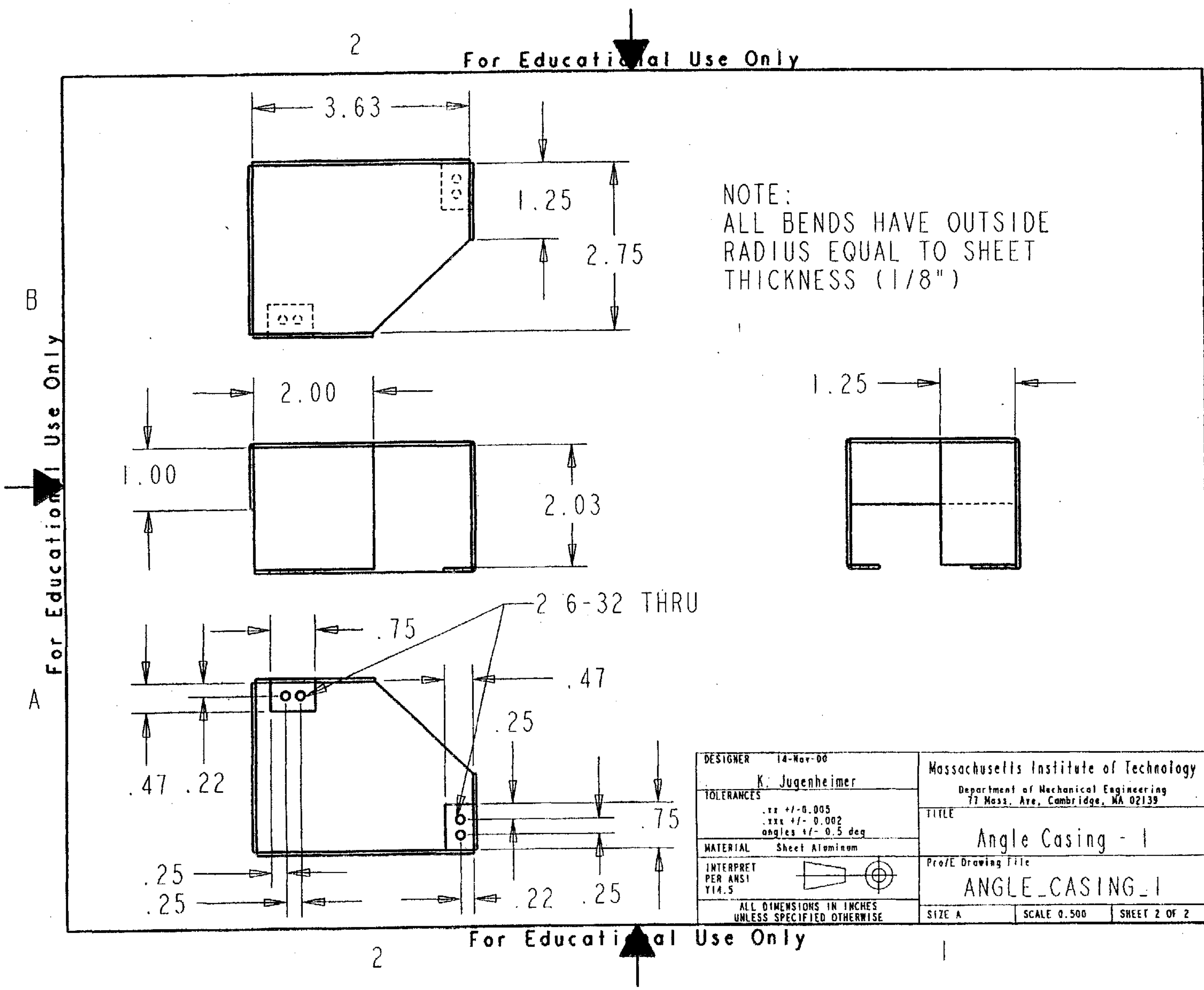
For Educational Use Only



ISOMETRIC VIEW

DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Angle Casing - 1
MATERIAL Sheet Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File ANGLE_CASING_1
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.750 | SHEET 1 OF 2

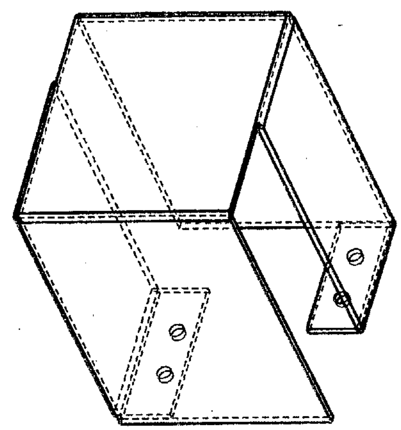
For Educational Use Only


For Educational Use Only
3.63
1.25
2.75
NOTE:
ALL BENDS HAVE OUTSIDE
RADIUS EQUAL TO SHEET
THICKNESS (1/8")
2.00
1.00
2.03
1.25
2 6-32 THRU
.75
.47
.25
.47 .22
.75
.25
.25
.22 .25
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Sheet Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Angle Casing - 1
Pro/E Drawing File
ANGLE_CASING_1
SIZE A
SCALE 0.500
SHEET 2 OF 2

2

B

A



ISOMETRIC VIEW

DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Angle Casing - 2
MATERIAL Sheet Aluminum	Pro/E Drawing File ANGLE_CASING_2
INTERPRET PER ANSI Y14.5	
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.750 | SHEET 1 OF 2

2

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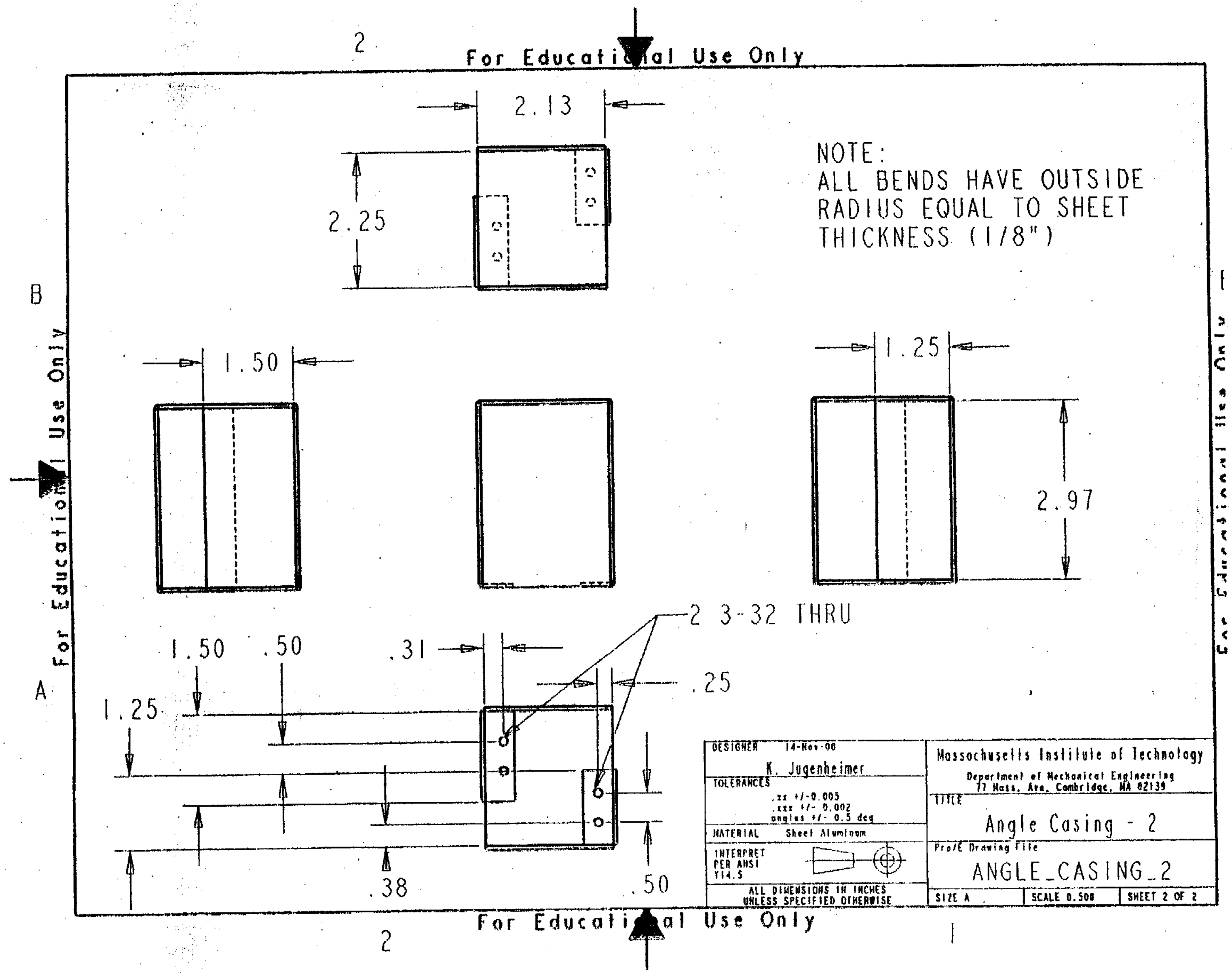

For Educational Use Only
2.13
2.25
NOTE:
ALL BENDS HAVE OUTSIDE
RADIUS EQUAL TO SHEET
THICKNESS (1/8")
1.50
1.25
2.97
2 3-32 THRU
1.50
.50
.31
.25
1.25
.38
.50
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Sheet Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Angle Casing - 2
Pro/E Drawing File
ANGLE_CASING_2
SIZE A
SCALE 0.500
SHEET 2 OF 2

11-7-00

2

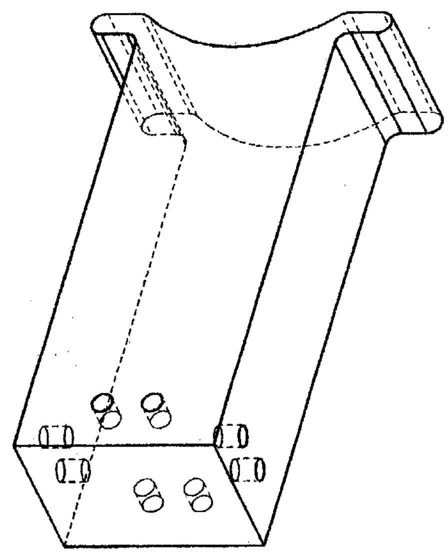
For Educational Use Only

B

E

For Educational Use Only

For Educational Use Only



ISOMETRIC VIEW

A

DESIGNER 07-Nov-00

K. Jugenheimer

TOLERANCES

xx +/-0.005

xxx +/- 0.002

angles +/- 0.5 deg

MATERIAL Aluminum

INTERPRET PER ANSI Y14.5

ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE

Massachusetts Institute of Technology

Department of Mechanical Engineering

77 Mass. Ave, Cambridge, MA 02139

TITLE

Arm Rest

Pro/E Drawing File

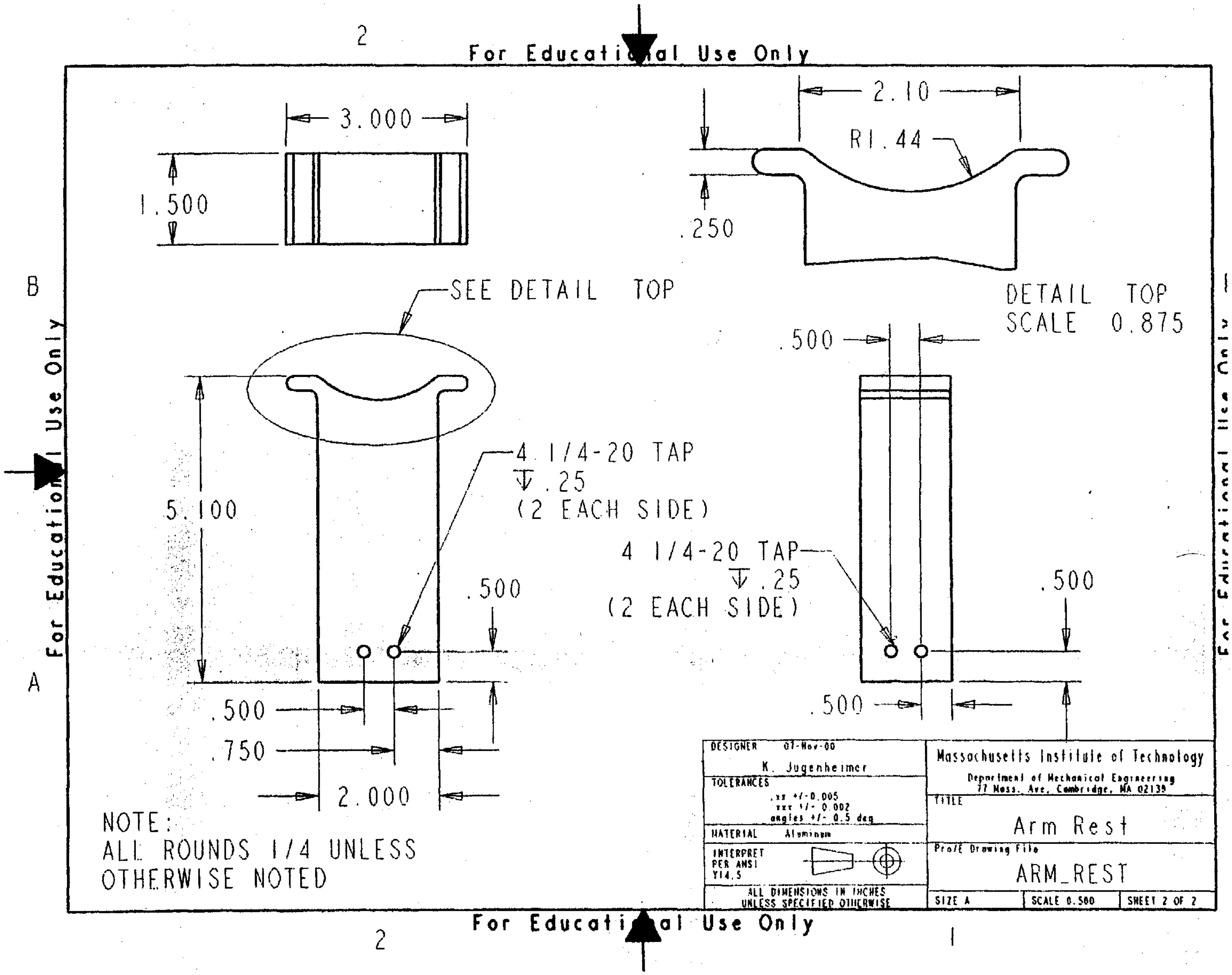
ARM_REST

SIZE A | SCALE 0.750 | SHEET 1 OF 2

For Educational Use Only

2

1


For Educational Use Only
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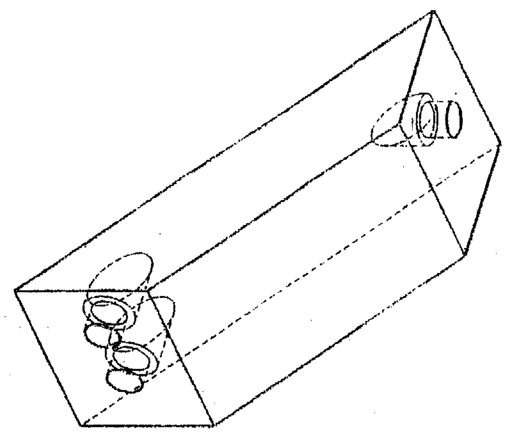
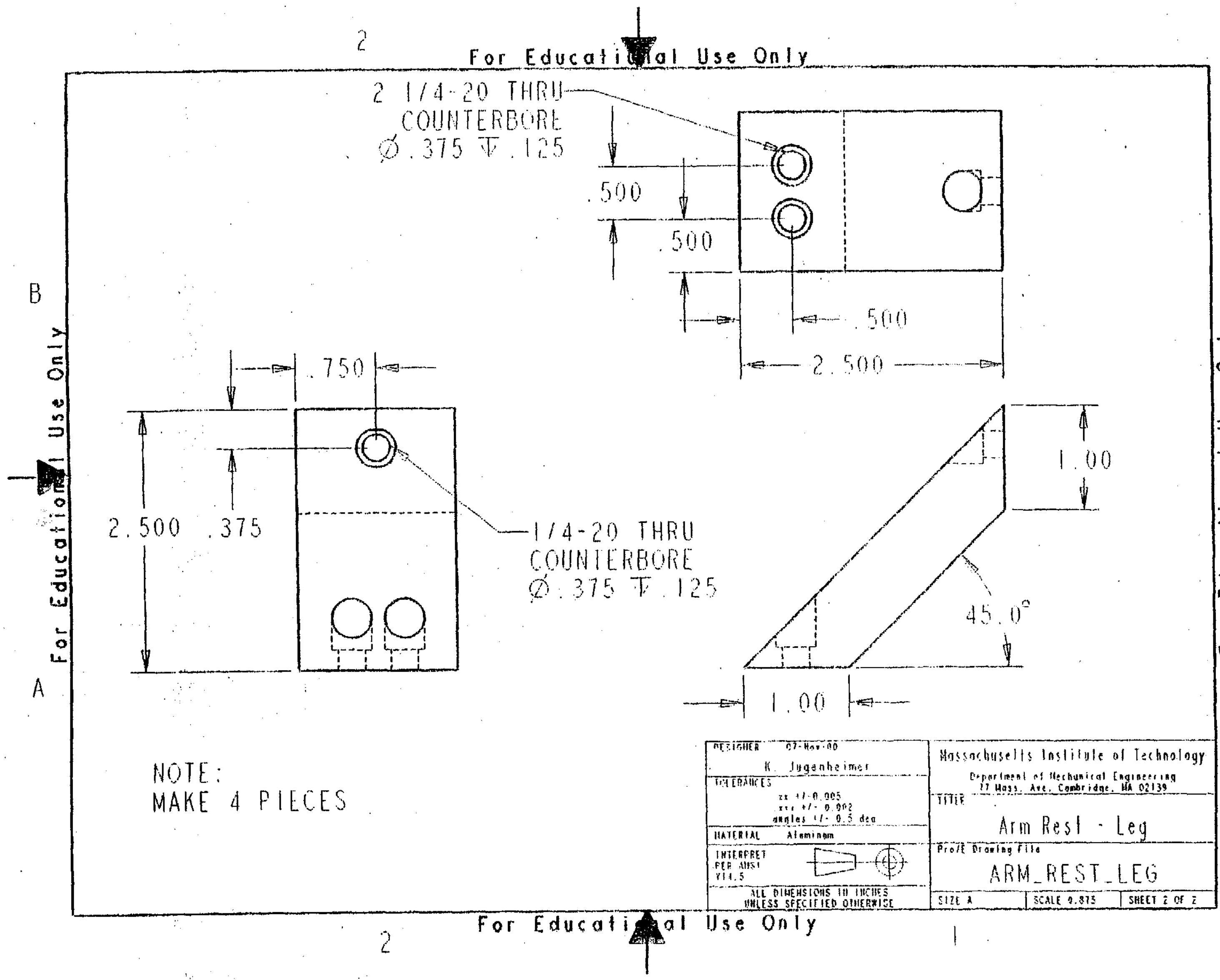
1.500
2.10
R1.44
.250
SEE DETAIL TOP
DETAIL TOP
SCALE 0.875
.500
5.100
4 1/4-20 TAP
⊽ .25
(2 EACH SIDE)
4 1/4-20 TAP
⊽ .25
(2 EACH SIDE)
.500
.500
.500
.750
2.000
.500
NOTE:
ALL ROUNDS 1/4 UNLESS
OTHERWISE NOTED
DESIGNER 07-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET
PER ANSI
Y14.5
ALL DIMENSIONS IN INCHES
UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Arm Rest
Pro/E Drawing File
ARM_REST
SIZE A
SCALE 0.500
SHEET 2 OF 2
For Educational Use Only



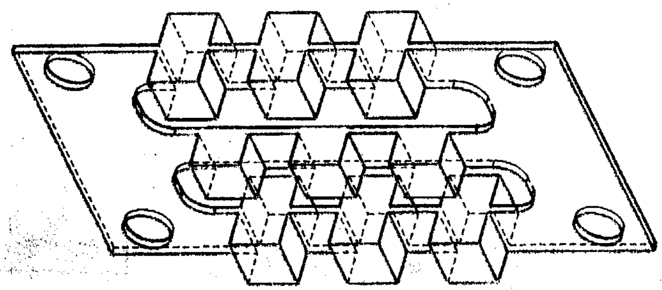
ISOMETRIC VIEW

DESIGNER 07-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02135
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Arm Rest - Leg
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File ARM_REST_LEG
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A	SCALE 1.000	SHEET 1 OF 2

For Educational Use Only


For Educational Use Only
2 1/4-20 THRU
COUNTERBORE
∅.375 ⊽.125
.500
.500
.500
2.500
.750
2.500
.375
1/4-20 THRU
COUNTERBORE
∅.375 ⊽.125
1.00
45.0°
1.00
NOTE:
MAKE 4 PIECES
DESIGNER 07-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Arm Rest - Leg
Pro/E Drawing File
ARM_REST_LEG
SIZE A
SCALE 0.875
SHEET 2 OF 2

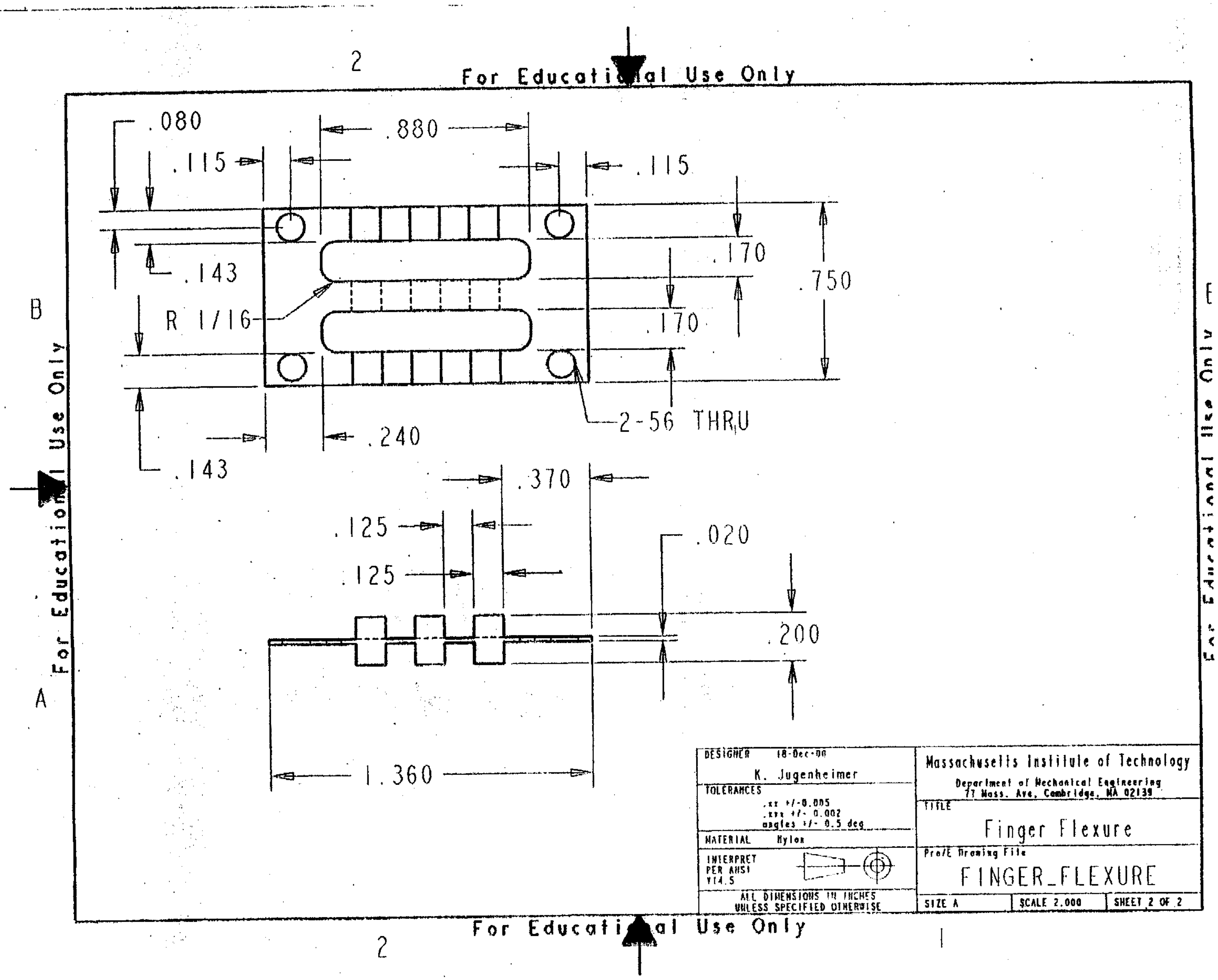
153



ISOMETRIC VIEW

DESIGNER 10-Jan-01 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Finger Flexure
MATERIAL Nylon	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File FINGER_FLEXURE
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 3.000 · SHEET 1 OF 2

For Educational Use Only

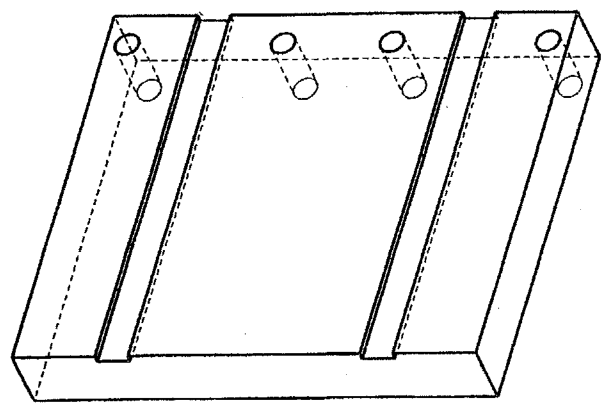

For Educational Use Only
.080
.880
.115
.115
.170
.750
.143
R 1/16
.170
2-56 THRU
.240
.143
.370
.125
.020
.125
.200
1.360
DESIGNER 18-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Nylon
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Finger Flexure
Pro/E Drawing File
FINGER_FLEXURE
SIZE A
SCALE 2.000
SHEET 2 OF 2

11-11-00

2

B

For Educational Use Only



ISOMETRIC VIEW

A

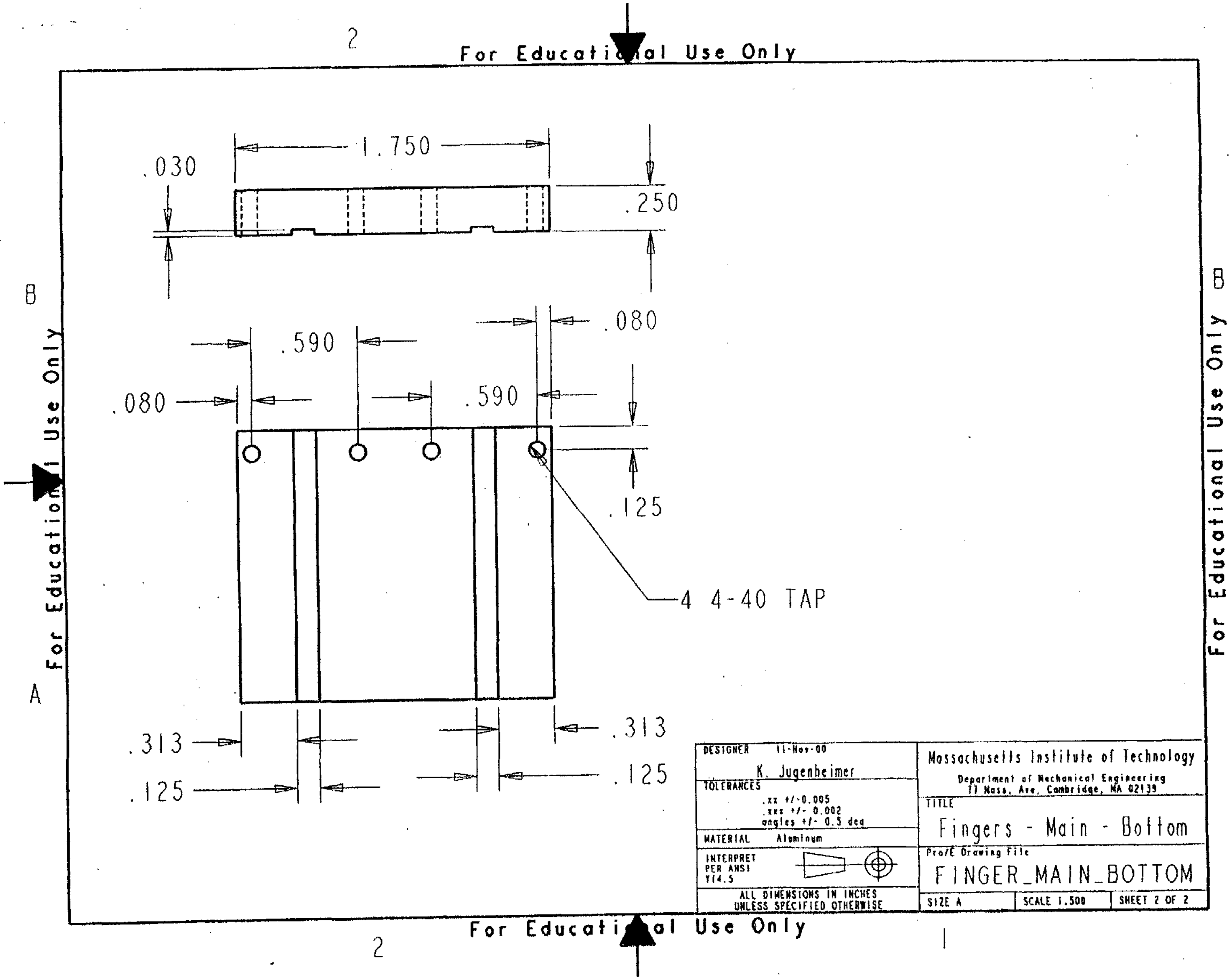
B

For Educational Use Only

DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Fingers - Main - Bottom
MATERIAL Aluminum	Pro/E Drawing File FINGER_MAIN_BOTTOM
INTERPRET PER ANSI Y14.5	SIZE A | SCALE 2.000 | SHEET 1 OF 2
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	

For Educational Use Only

2 1


For Educational Use Only
2
1.750
.030
.250
B
.590
.080
.080
.590
.125
4 4-40 TAP
A
.313
.313
.125
.125
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Fingers - Main - Bottom
Pro/E Drawing File
FINGER_MAIN_BOTTOM
SIZE A
SCALE 1.500
SHEET 2 OF 2
1

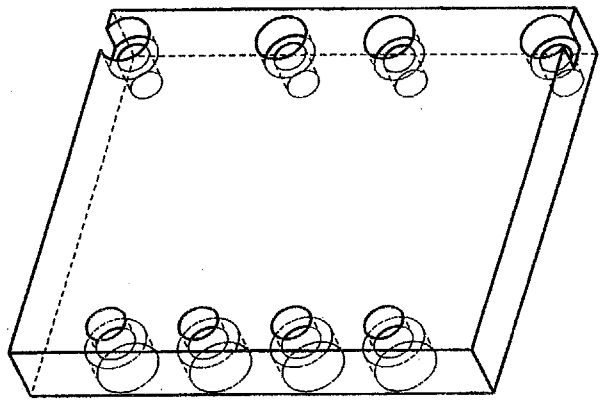
11-11-00

2

B

For Educational Use Only

For Educational Use Only



ISOMETRIC VIEW

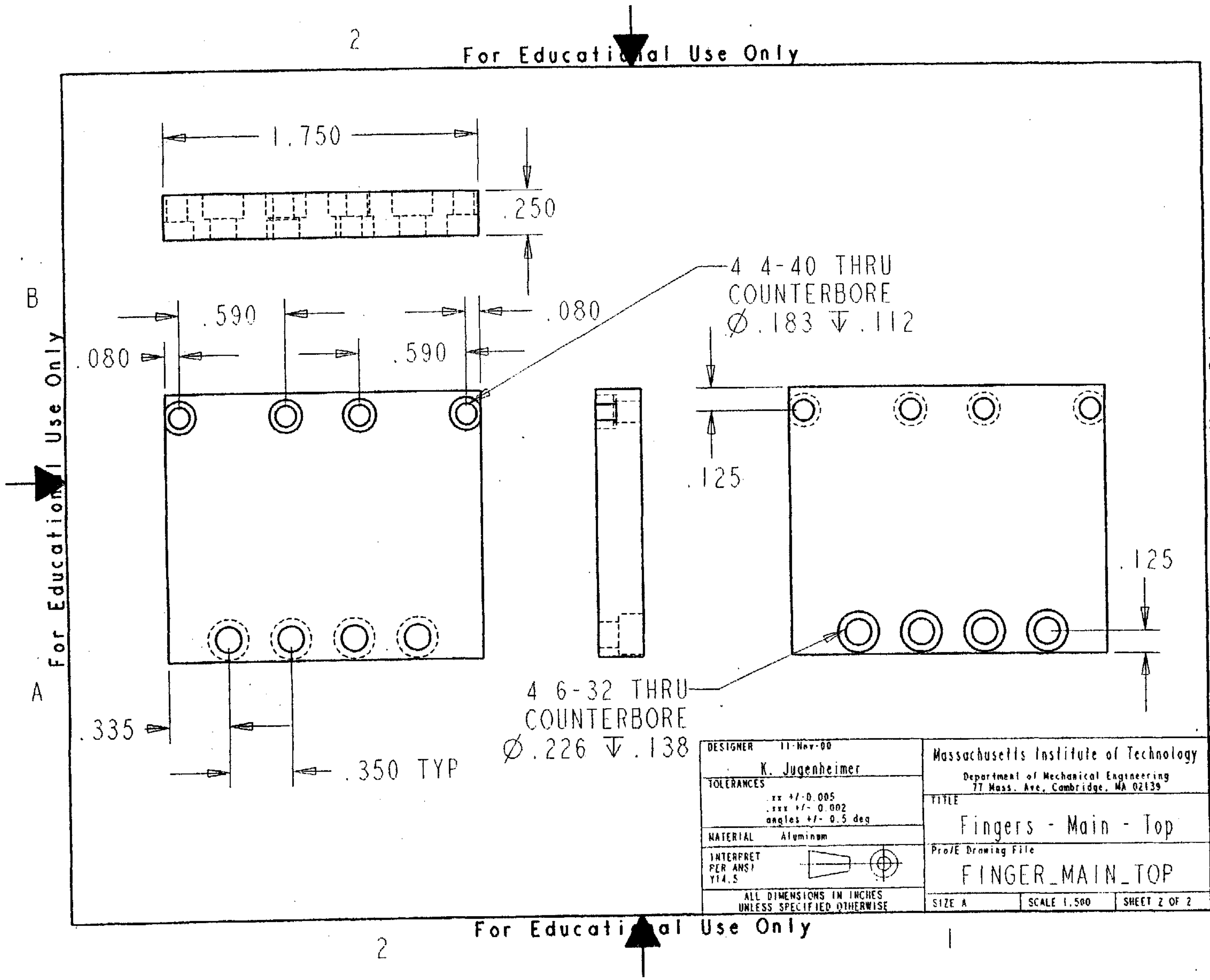
A

DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Fingers - Main - Top
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File FINGER_MAIN_TOP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 2

For Educational Use Only

2

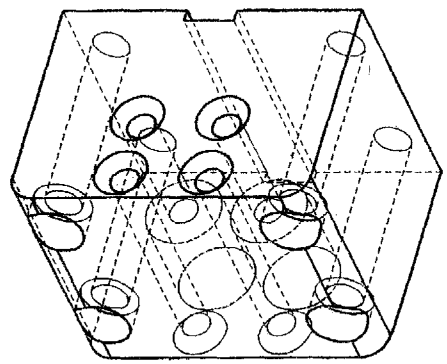
1


For Educational Use Only
2
B
A
1.750
.250
.080
.590
.590
.080
4 4-40 THRU
COUNTERBORE
∅.183 ↧.112
.125
.125
4 6-32 THRU
COUNTERBORE
∅.226 ↧.138
.335
.350 TYP
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Fingers - Main - Top
Pro/E Drawing File
FINGER_MAIN_TOP
SIZE A
SCALE 1.500
SHEET 2 OF 2
1

2

B

For Educational Use Only



ISOMETRIC VIEW

A

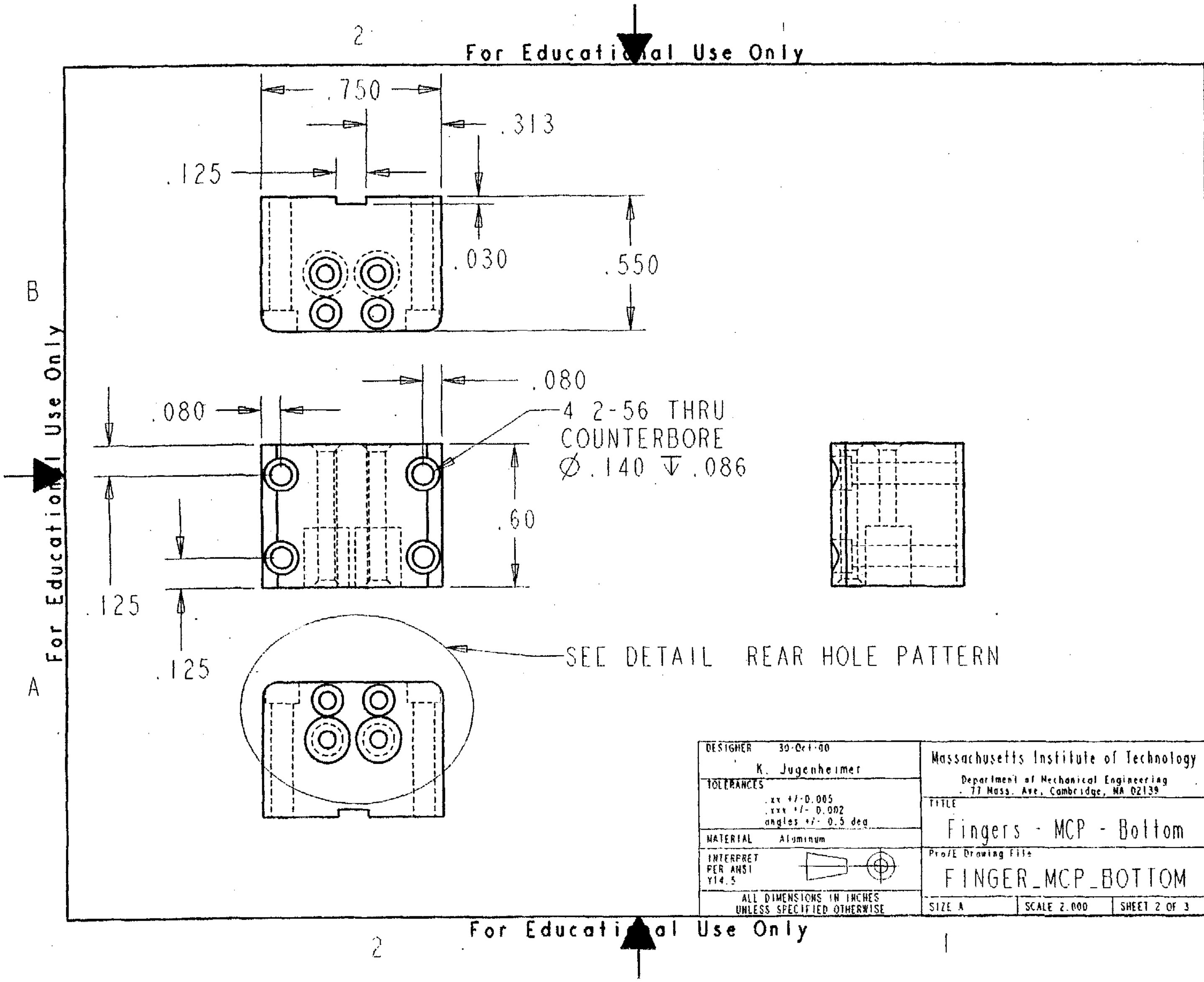
DESIGNER 05-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Fingers - MCP - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File FINGER_MCP_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 3.000 / SHEET 1 OF 3

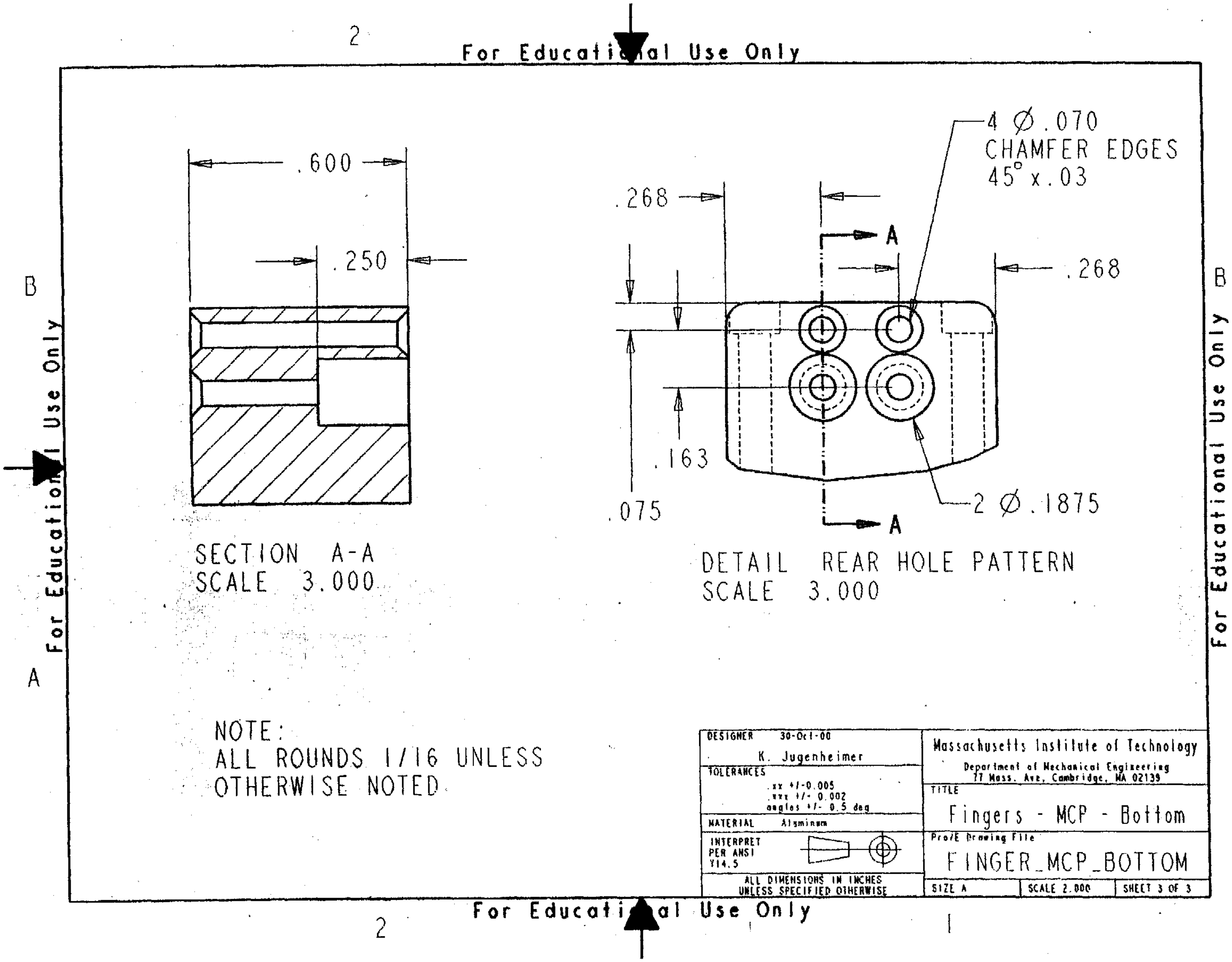
For Educational Use Only

B

For Educational Use Only

2 1

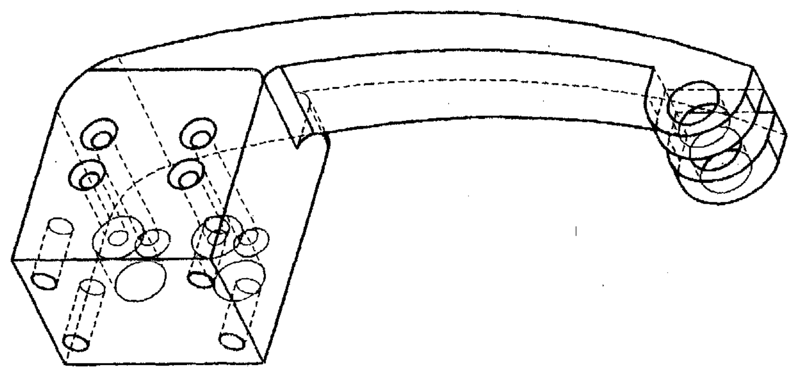

For Educational Use Only
.750
.313
.125
.030
.550
.080
.080
4 2-56 THRU
COUNTERBORE
∅.140 ↧.086
.60
.125
.125
SEE DETAIL REAR HOLE PATTERN
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Fingers - MCP - Bottom
Pro/E Drawing File
FINGER_MCP_BOTTOM
SIZE A
SCALE 2.000
SHEET 2 OF 3


For Educational Use Only
.600
.250
SECTION A-A
SCALE 3.000
4 Ø.070
CHAMFER EDGES
45° x.03
.268
.268
.163
.075
2 Ø.1875
A
A
DETAIL REAR HOLE PATTERN
SCALE 3.000
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Fingers - MCP - Bottom
Pro/E Drawing File
FINGER_MCP_BOTTOM
SIZE A
SCALE 2.000
SHEET 3 OF 3

2

B

For Educational Use Only



ISOMETRIC VIEW

For Educational Use Only

B

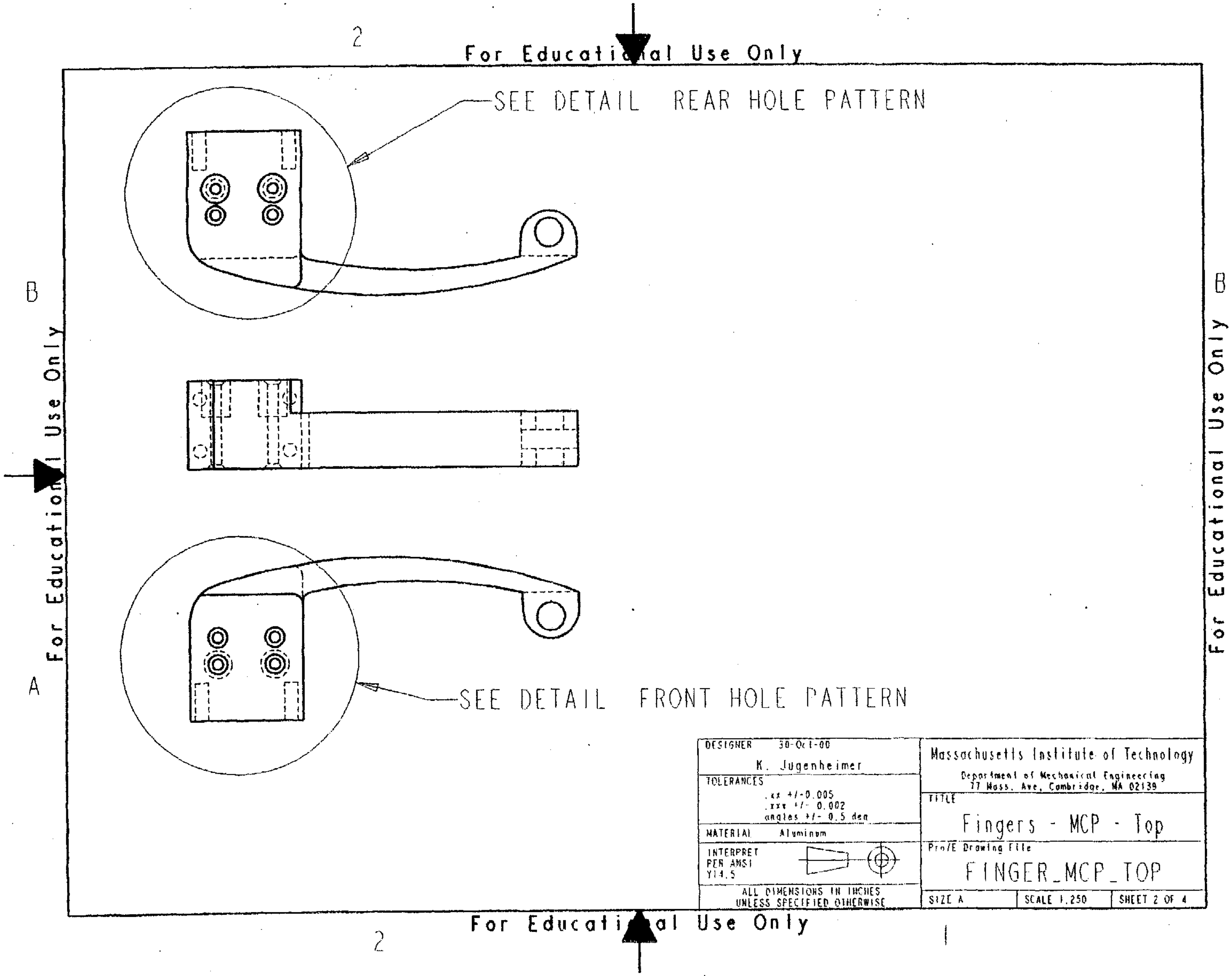
A

DESIGNER 05-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Fingers - MCP - Top
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File FINGER_MCP_TOP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 4

For Educational Use Only

2

1



For Educational Use Only
2
SEE DETAIL REAR HOLE PATTERN
B
A
SEE DETAIL FRONT HOLE PATTERN
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Fingers - MCP - Top
Pro/E Drawing File
FINGER_MCP_TOP
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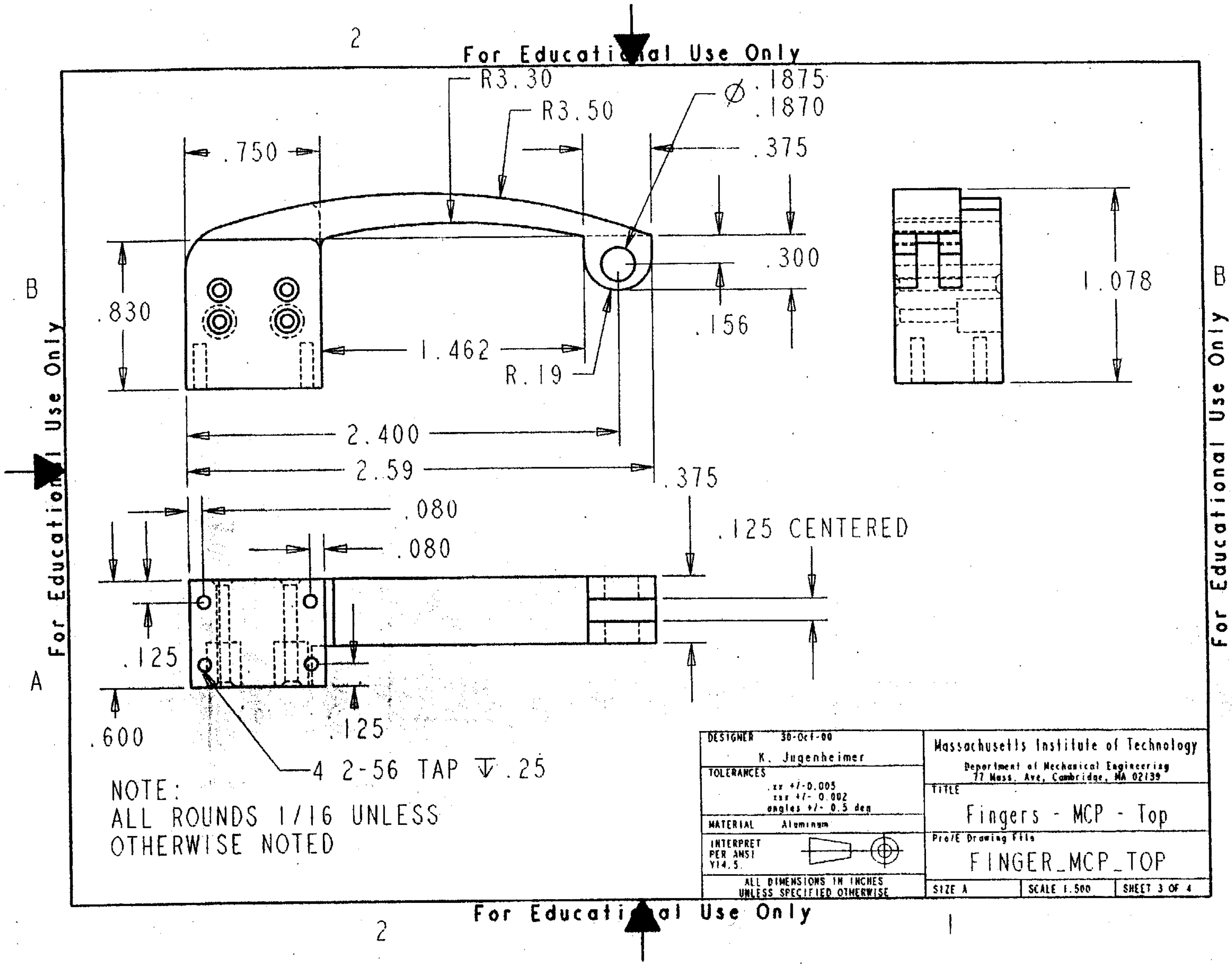
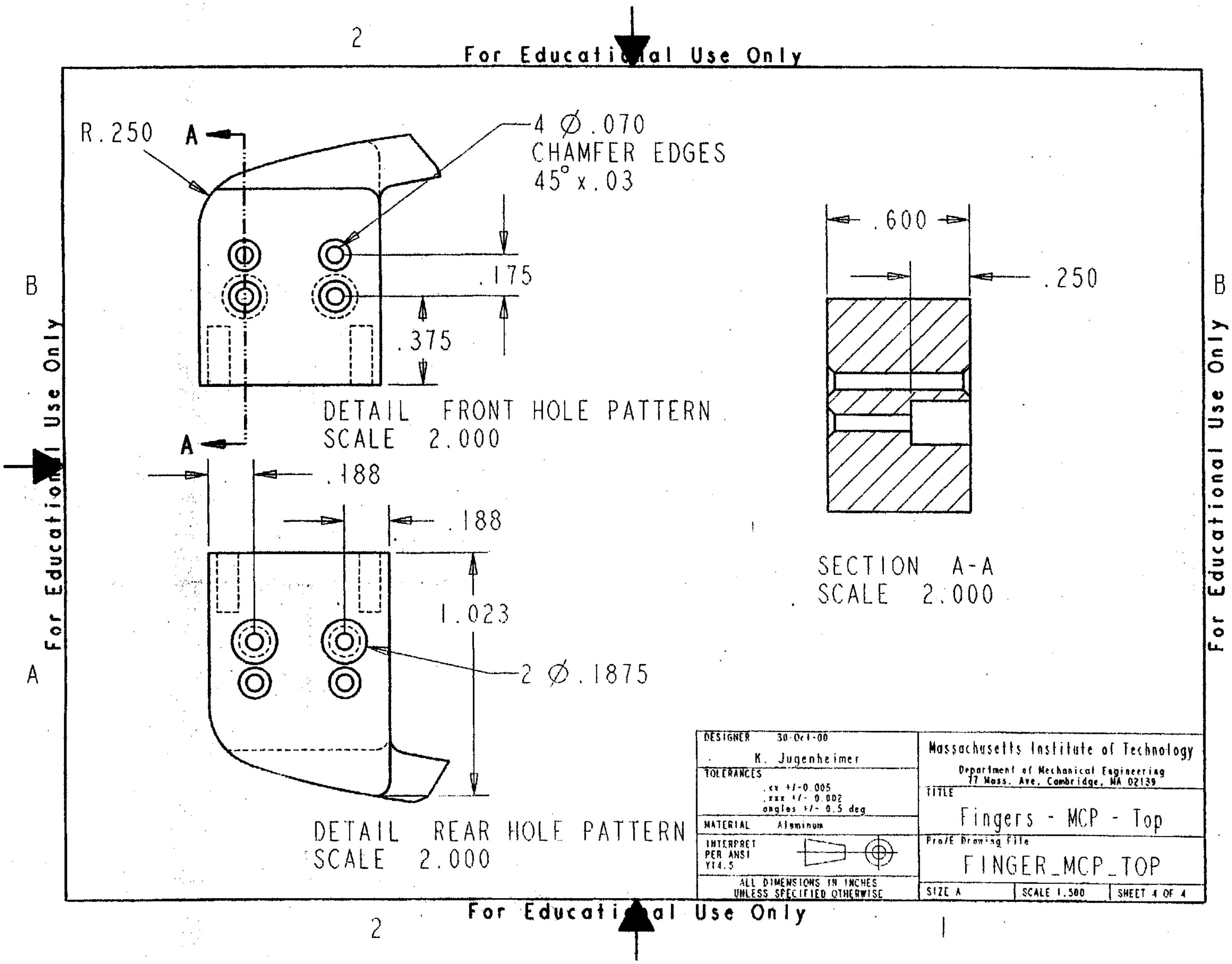
SCALE 1.250
SHEET 2 OF 4
1


For Educational Use Only
R3.30
R3.50
Ø .1875 .1870
.750
.375
.300
.830
.156
1.462
R.19
1.078
2.400
2.59
.375
.080
.080
.125 CENTERED
.125
.600
.125
4 2-56 TAP ↧ .25
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5.
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Fingers - MCP - Top
Pro/E Drawing File
FINGER_MCP_TOP
SIZE A
SCALE 1.500
SHEET 3 OF 4

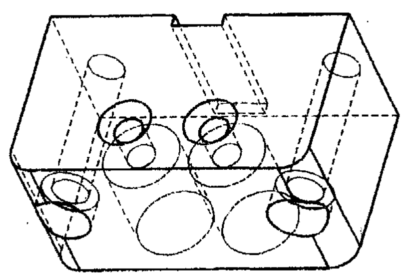

For Educational Use Only
R.250
A
4 Ø.070
CHAMFER EDGES
45° x.03
.175
.375
.600
.250
DETAIL FRONT HOLE PATTERN
SCALE 2.000
.188
.188
1.023
2 Ø.1875
SECTION A-A
SCALE 2.000
DETAIL REAR HOLE PATTERN
SCALE 2.000
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Fingers - MCP - Top
Pro/E Drawing File
FINGER_MCP_TOP
SIZE A
SCALE 1.500
SHEET 4 OF 4

11-7-00

2

B

For Educational Use Only



ISOMETRIC VIEW

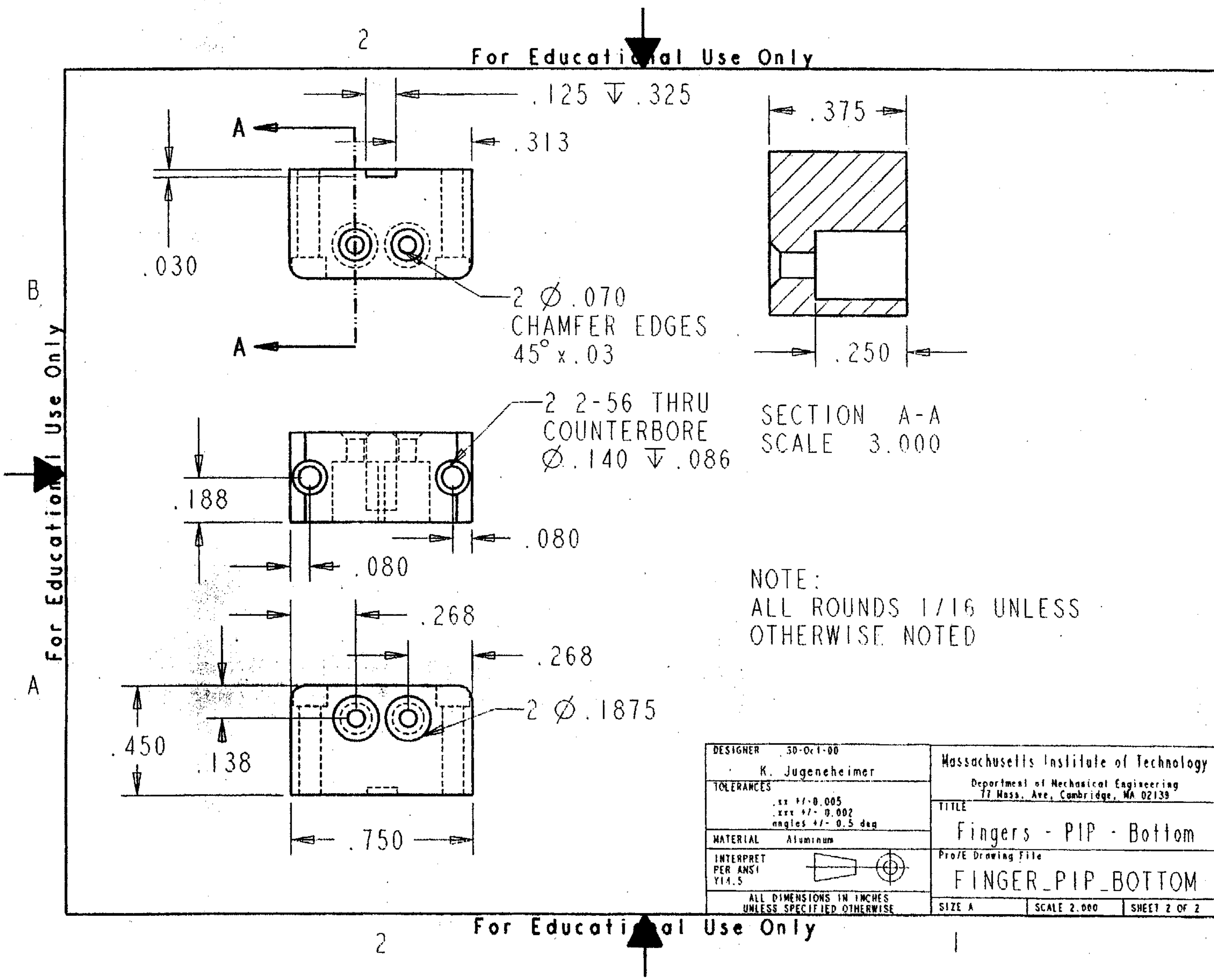
A

DESIGNER 05-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Fingers - PIP - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File FINGER_PIP_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 3.000 | SHEET 1 OF 2

For Educational Use Only

2 1

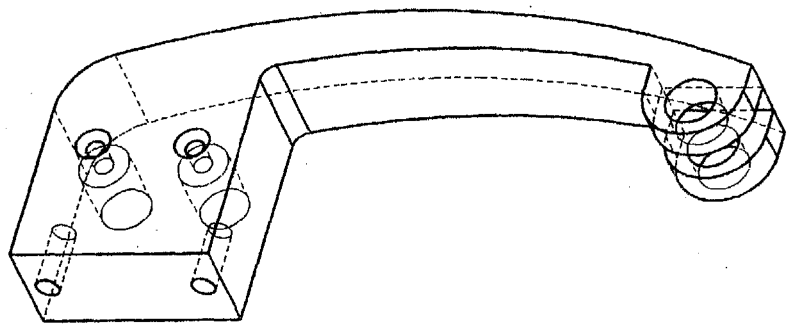
For Educational Use Only



For Educational Use Only
.125 ⊽ .325
.313
.030
A
2 ∅.070
CHAMFER EDGES
45° x .03
.375
.250
SECTION A-A
SCALE 3.000
2 2-56 THRU
COUNTERBORE
∅.140 ⊽ .086
.188
.080
.080
.268
.268
2 ∅.1875
.450
.138
.750
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 30-Oct-00
K. Jugeneheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Fingers - PIP - Bottom
Pro/E Drawing File
FINGER_PIP_BOTTOM
SIZE A
SCALE 2.000
SHEET 2 OF 2

2

B

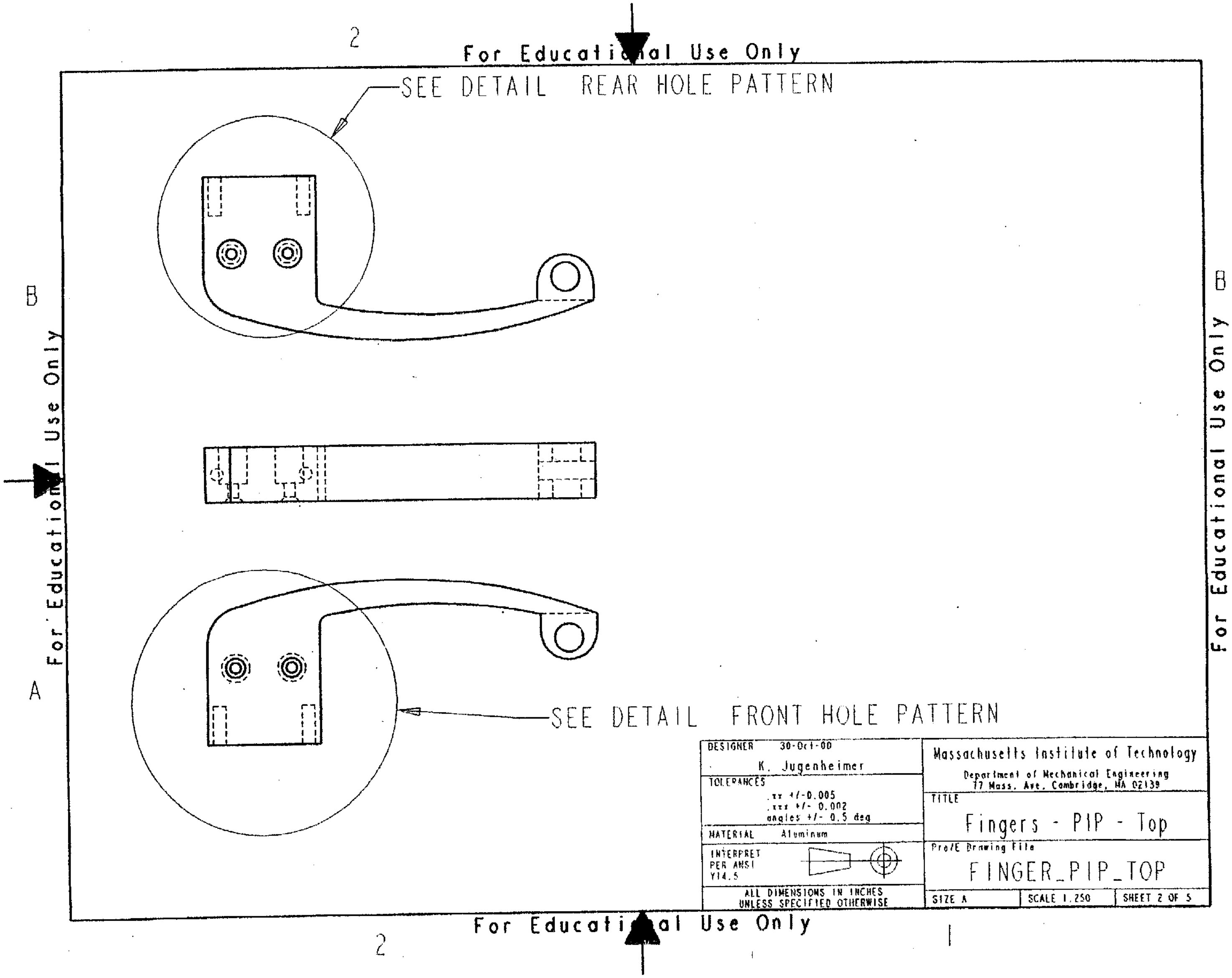


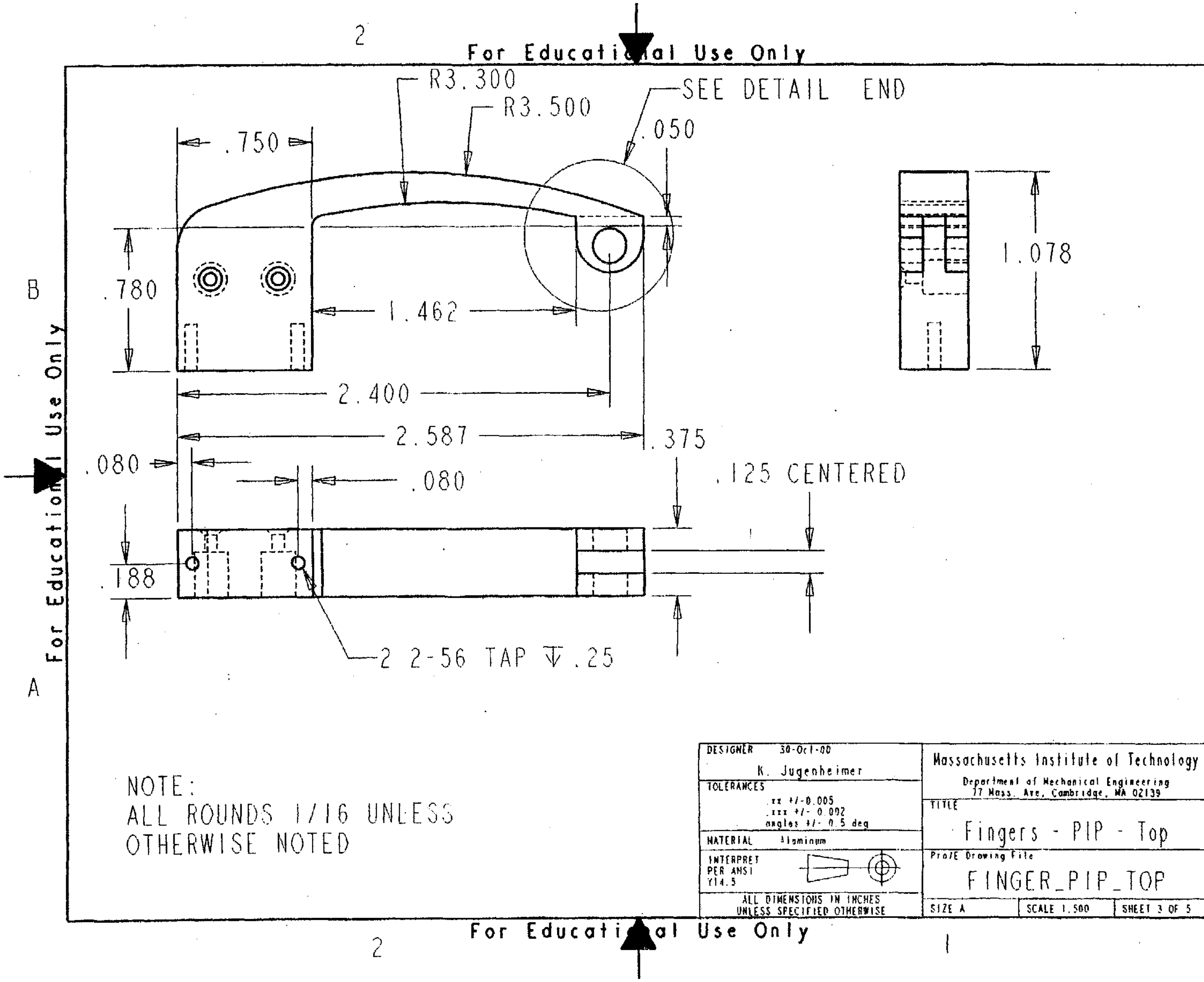
ISOMETRIC VIEW

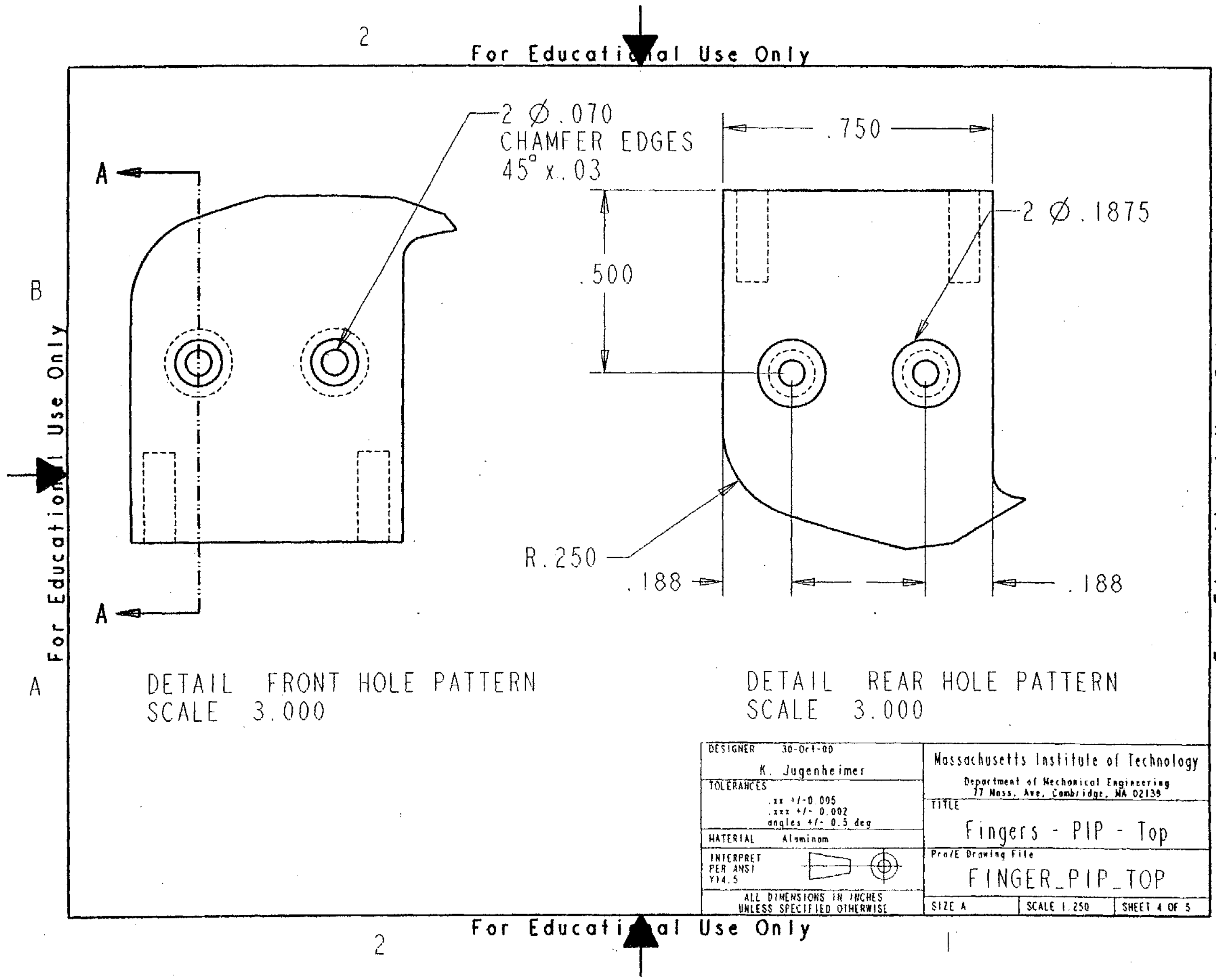
A

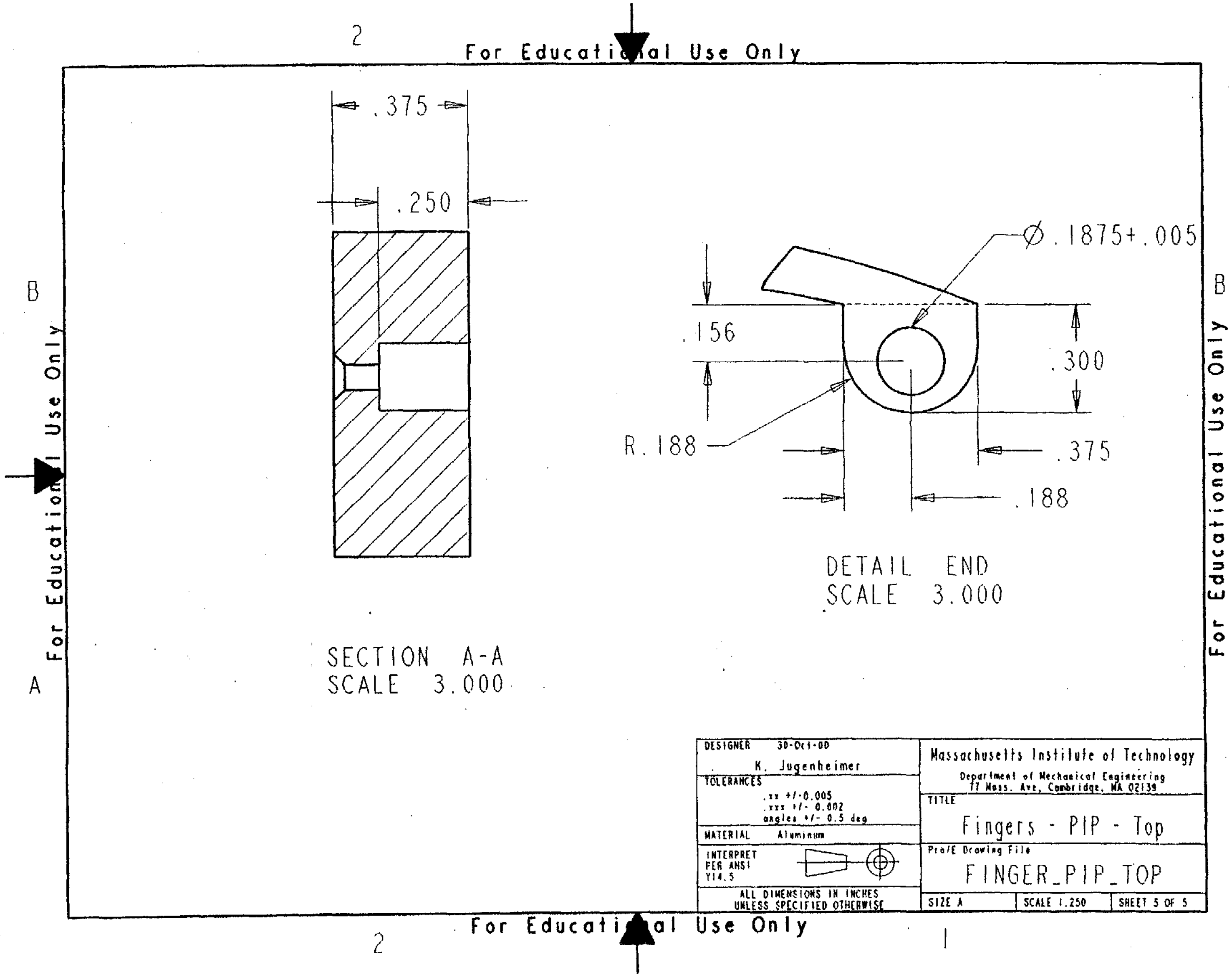
DESIGNER 05-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Fingers - PIP - Top
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File FINGER_PIP_TOP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 5

2 1


For Educational Use Only
SEE DETAIL REAR HOLE PATTERN
SEE DETAIL FRONT HOLE PATTERN
2
B
A
1
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Fingers - PIP - Top
Pro/E Drawing File
FINGER_PIP_TOP
SIZE A
SCALE 1.250
SHEET 2 OF 5


For Educational Use Only
R3.300
R3.500
SEE DETAIL END
.750
.050
.780
1.462
1.078
2.400
2.587
.375
.080
.080
.125 CENTERED
.188
2 2-56 TAP ⊽ .25
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Fingers - PIP - Top
Pro/E Drawing File
FINGER_PIP_TOP
SIZE A
SCALE 1.500
SHEET 3 OF 5


For Educational Use Only
2 Ø .070
CHAMFER EDGES
45° x .03
.750
.500
2 Ø .1875
R.250
.188
.188
A
A
B
B
A
2
2
1
DETAIL FRONT HOLE PATTERN
SCALE 3.000
DETAIL REAR HOLE PATTERN
SCALE 3.000
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Fingers - PIP - Top
Pro/E Drawing File
FINGER_PIP_TOP
SIZE A
SCALE 1.250
SHEET 4 OF 5

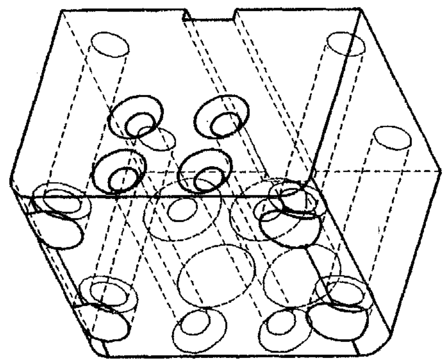

For Educational Use Only
.375
.250
SECTION A-A
SCALE 3.000
∅.1875+.005
.156
.300
R.188
.375
.188
DETAIL END
SCALE 3.000
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Fingers - PIP - Top
Pro/E Drawing File
FINGER_PIP_TOP
SIZE A
SCALE 1.250
SHEET 5 OF 5

2

For Educational Use Only

B

For Educational Use Only



ISOMETRIC VIEW

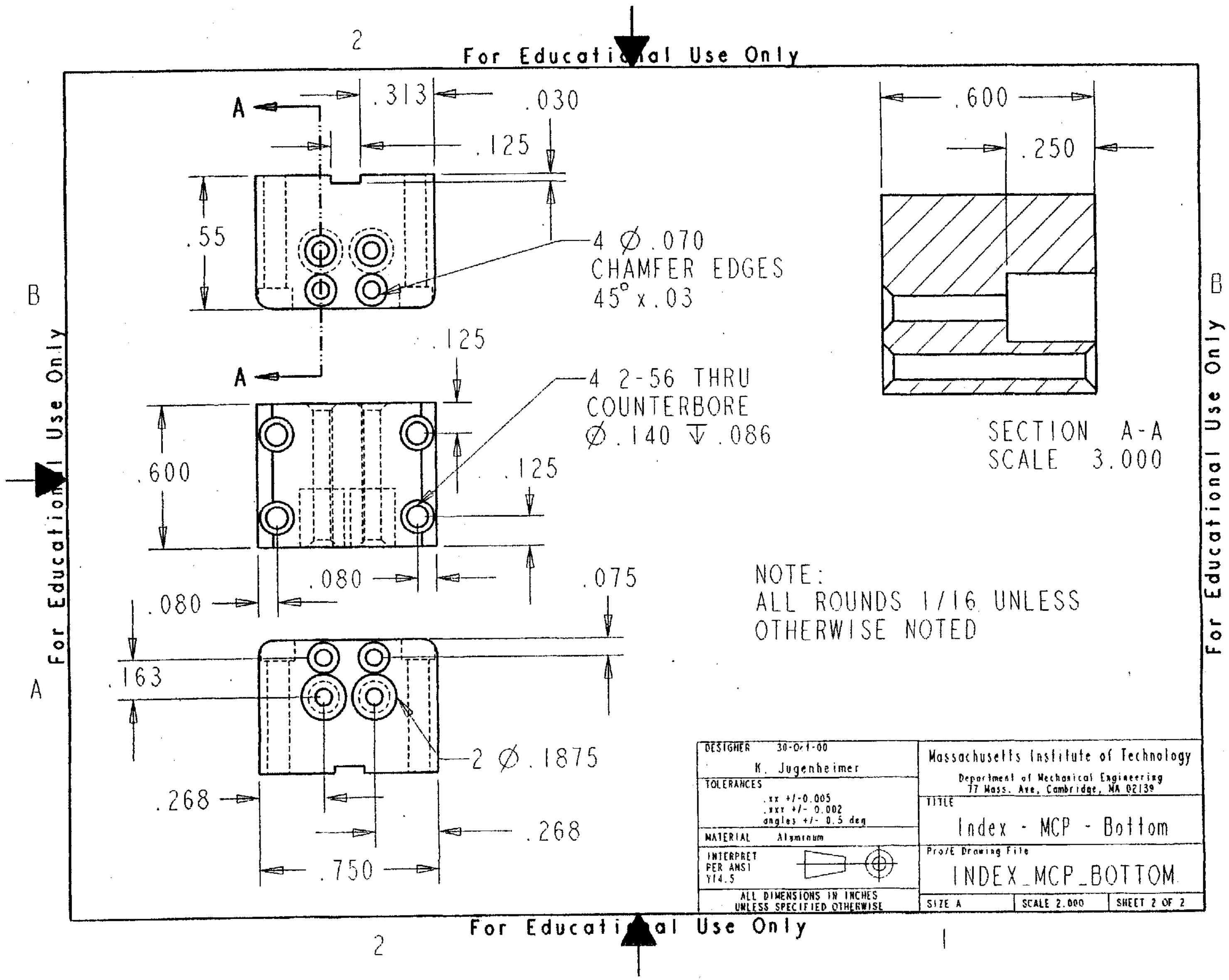
A

DESIGNER 05-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - MCP - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File INDEX_MCP_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 3.000 / SHEET 1 OF 2

For Educational Use Only

2

1


For Educational Use Only
.313
.030
.125
.55
4 ∅ .070
CHAMFER EDGES
45° x .03
A
A
.125
4 2-56 THRU
COUNTERBORE
∅ .140 ↧ .086
.600
.125
.080
.075
.080
.163
2 ∅ .1875
.268
.268
.750
.600
.250
SECTION A-A
SCALE 3.000
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Index - MCP - Bottom
Pro/E Drawing File
INDEX_MCP_BOTTOM
SIZE A
SCALE 2.000
SHEET 2 OF 2
For Educational Use Only

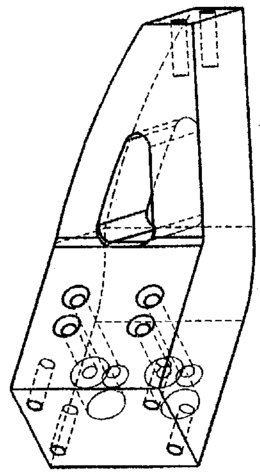
2

B

A

For Educational Use Only

For Educational Use Only

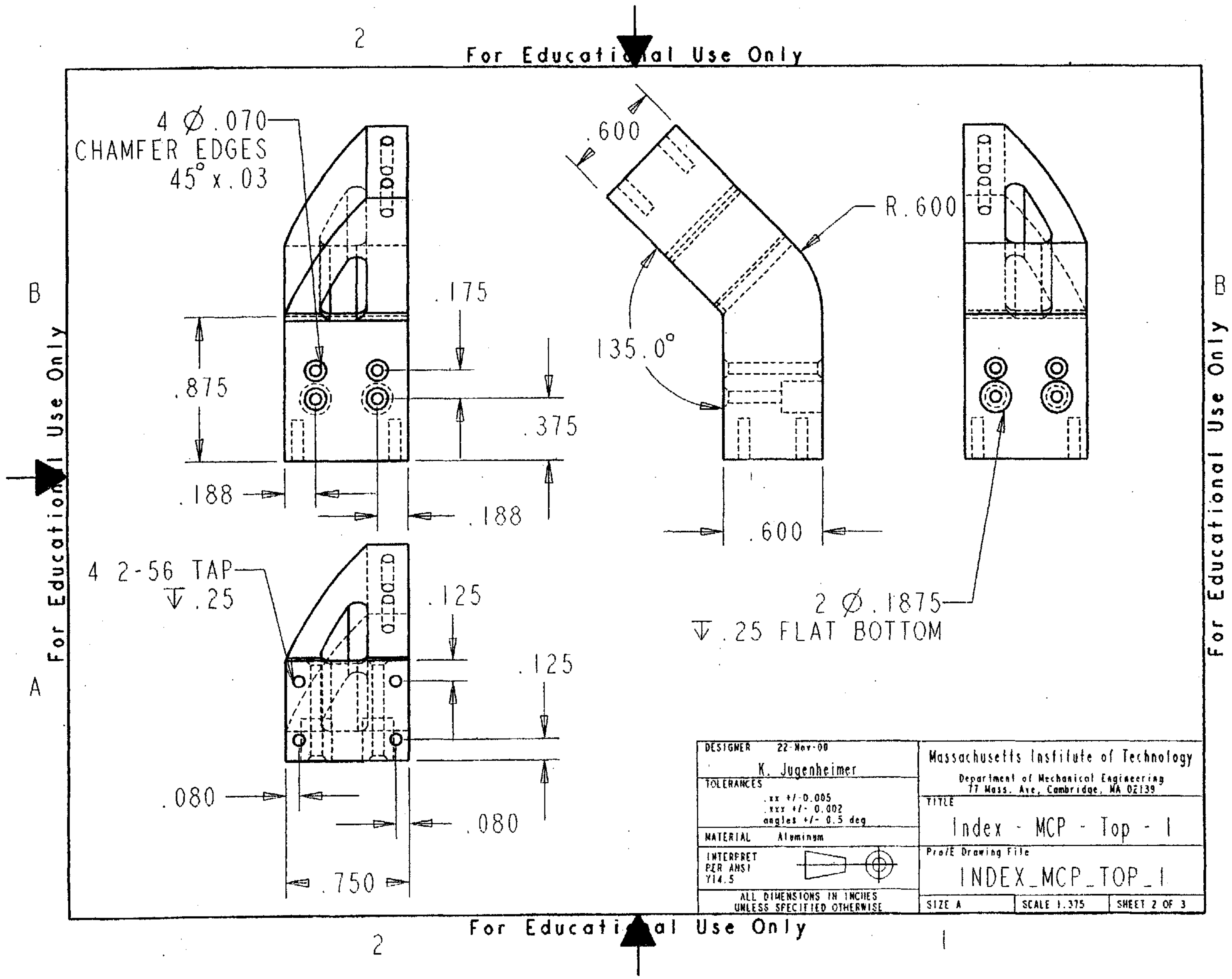


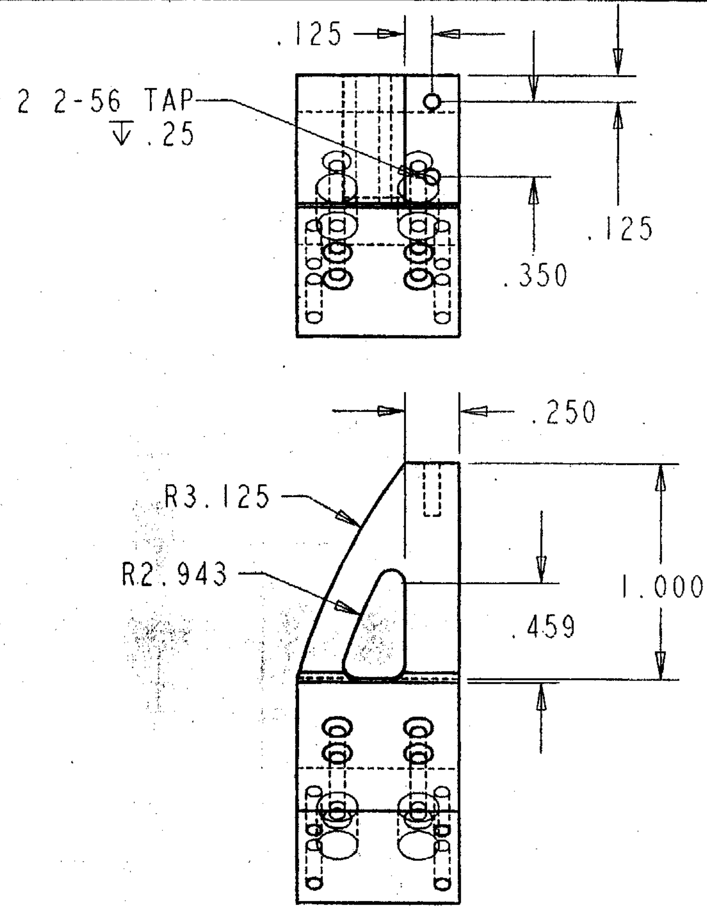
ISOMETRIC VIEW

DESIGNER 22-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - MCP - Top - 1
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File INDEX_MCP_TOP_1
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.500 | SHEET 1 OF 3

For Educational Use Only

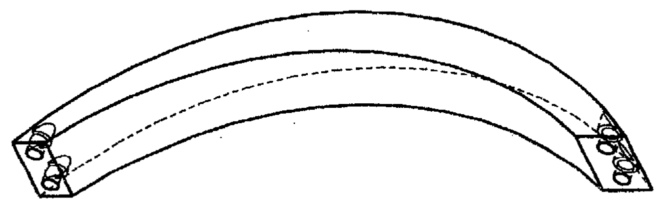
2 1


For Educational Use Only
4 Ø .070
CHAMFER EDGES
45° x .03
.600
R.600
.175
.875
.375
135.0°
.188
.188
.600
4 2-56 TAP
↧ .25
.125
.125
2 Ø .1875
↧ .25 FLAT BOTTOM
.080
.080
.750
DESIGNER 22-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Index - MCP - Top - 1
Pro/E Drawing File
INDEX_MCP_TOP_1
SIZE A
SCALE 1.375
SHEET 2 OF 3



NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED

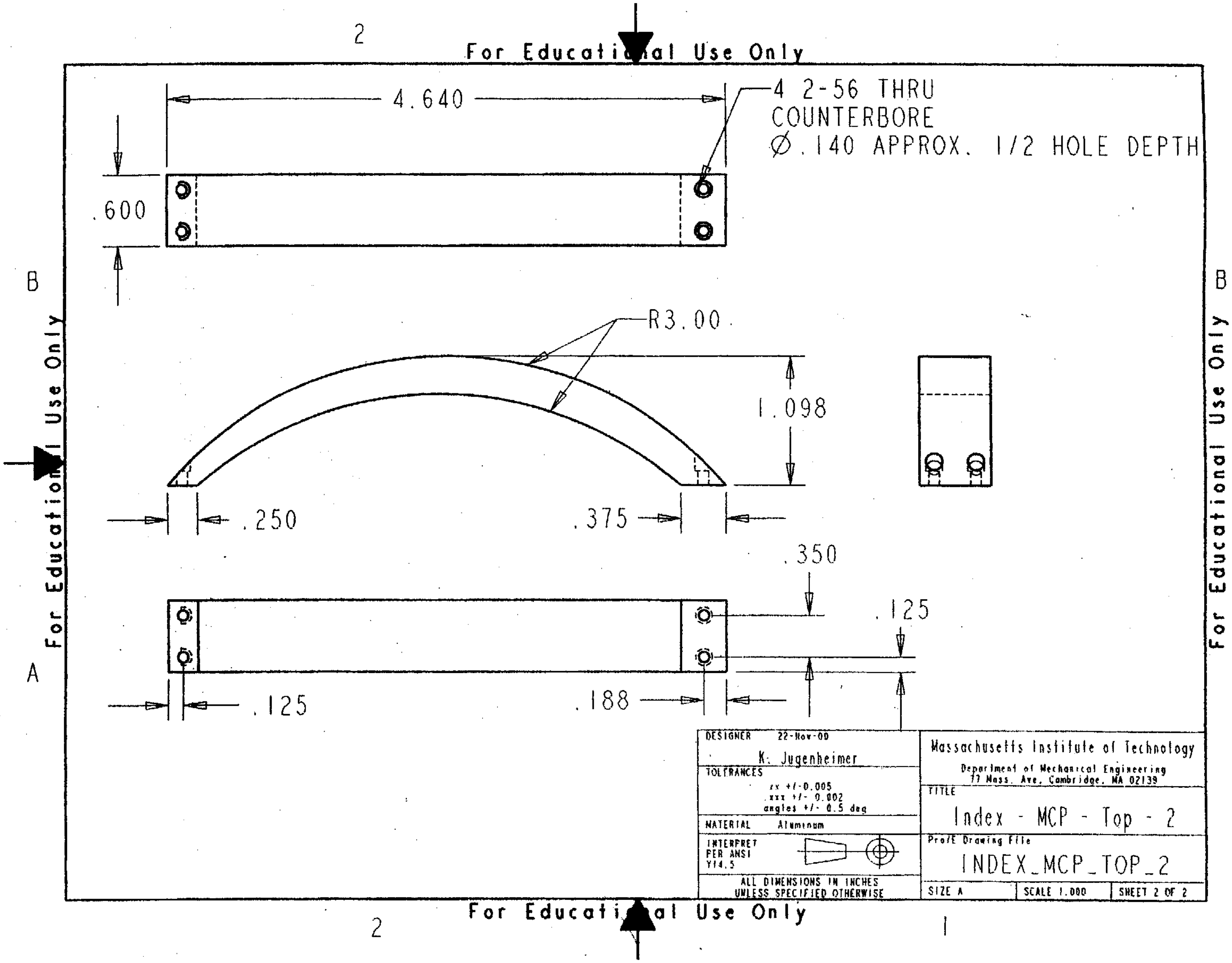
DESIGNER 22-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - MCP - Top - 1
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File INDEX_MCP_TOP_1
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.500 | SHEET 3 OF 3



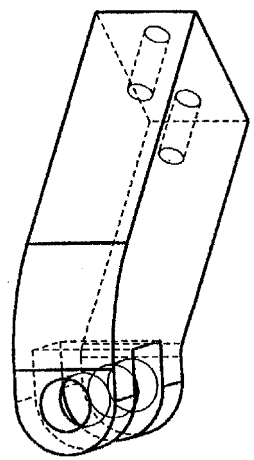
ISOMETRIC VIEW

DESIGNER 22-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - MCP - Top - 2
MATERIAL Aluminum	Pro/E Drawing File INDEX_MCP_TOP_2
INTERPRET PER ANSI Y14.5 ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.000 | SHEET 1 OF 2

For Educational Use Only
For Educational Use Only
For Educational Use Only

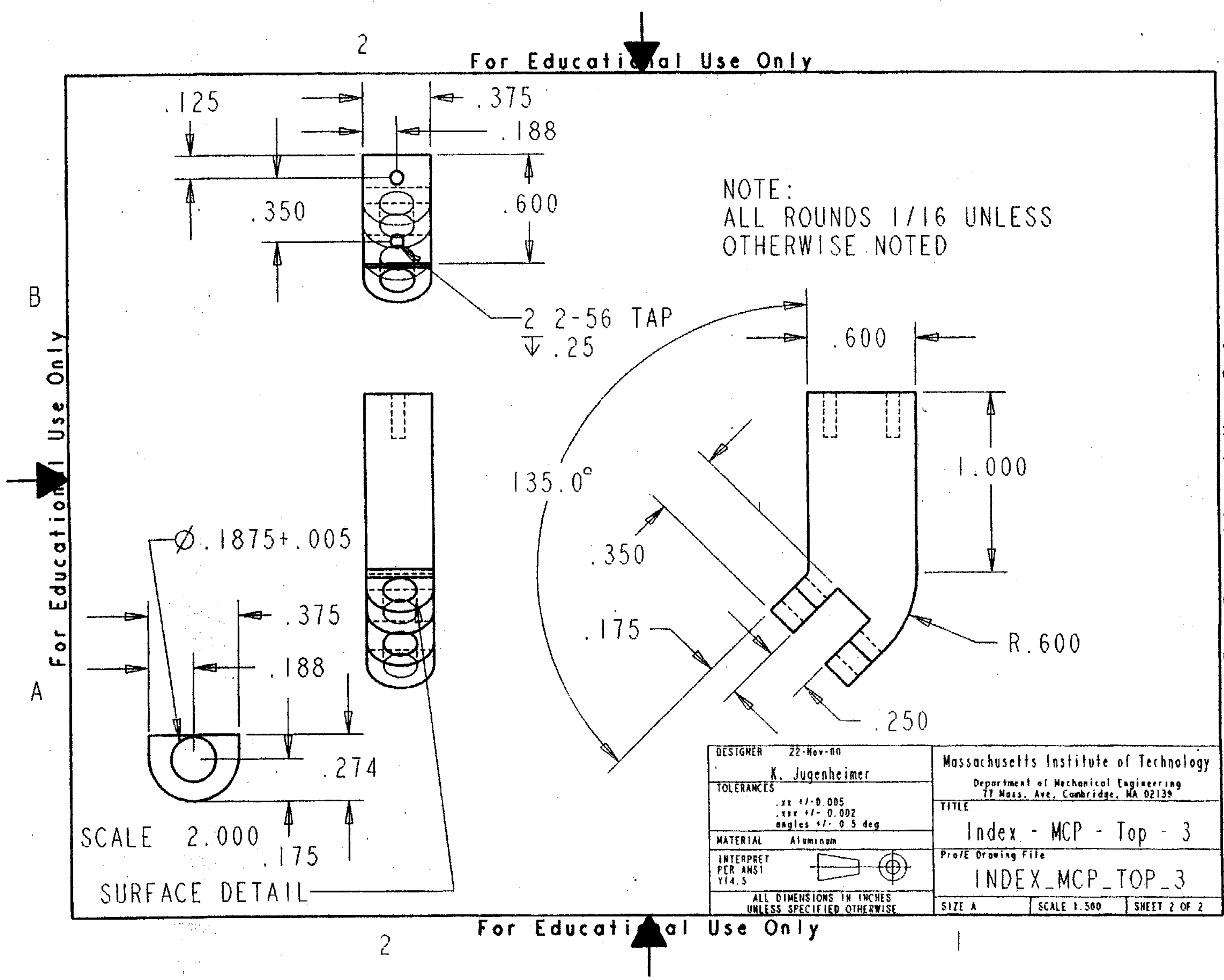


2
For Educational Use Only
4.640
4 2-56 THRU
COUNTERBORE
Ø.140 APPROX. 1/2 HOLE DEPTH
.600
B
R3.00
1.098
.250
.375
.350
.125
A
.125
.188
DESIGNER 22-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Index - MCP - Top - 2
Pro/E Drawing File
INDEX_MCP_TOP_2
SIZE A
SCALE 1.000
SHEET 2 OF 2
For Educational Use Only
2
1



ISOMETRIC VIEW

DESIGNER 22-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - MCP - Top - 3
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File INDEX_MCP_TOP_3
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 2


For Educational Use Only
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
2 2-56 TAP
.25
.125
.375
.188
.350
.600
135.0°
1.000
R.600
.175
.250
Ø.1875+.005
.274
SCALE 2.000
SURFACE DETAIL
DESIGNER 22-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Index - MCP - Top - 3
Pro/E Drawing File
INDEX_MCP_TOP_3
SIZE A
SCALE 1.500
SHEET 2 OF 2

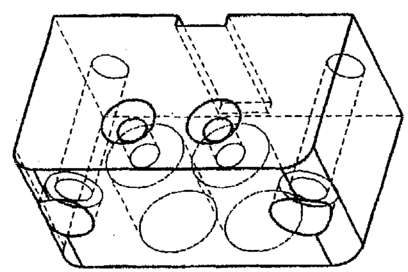
RG

11-7-00

2

For Educational Use Only

B



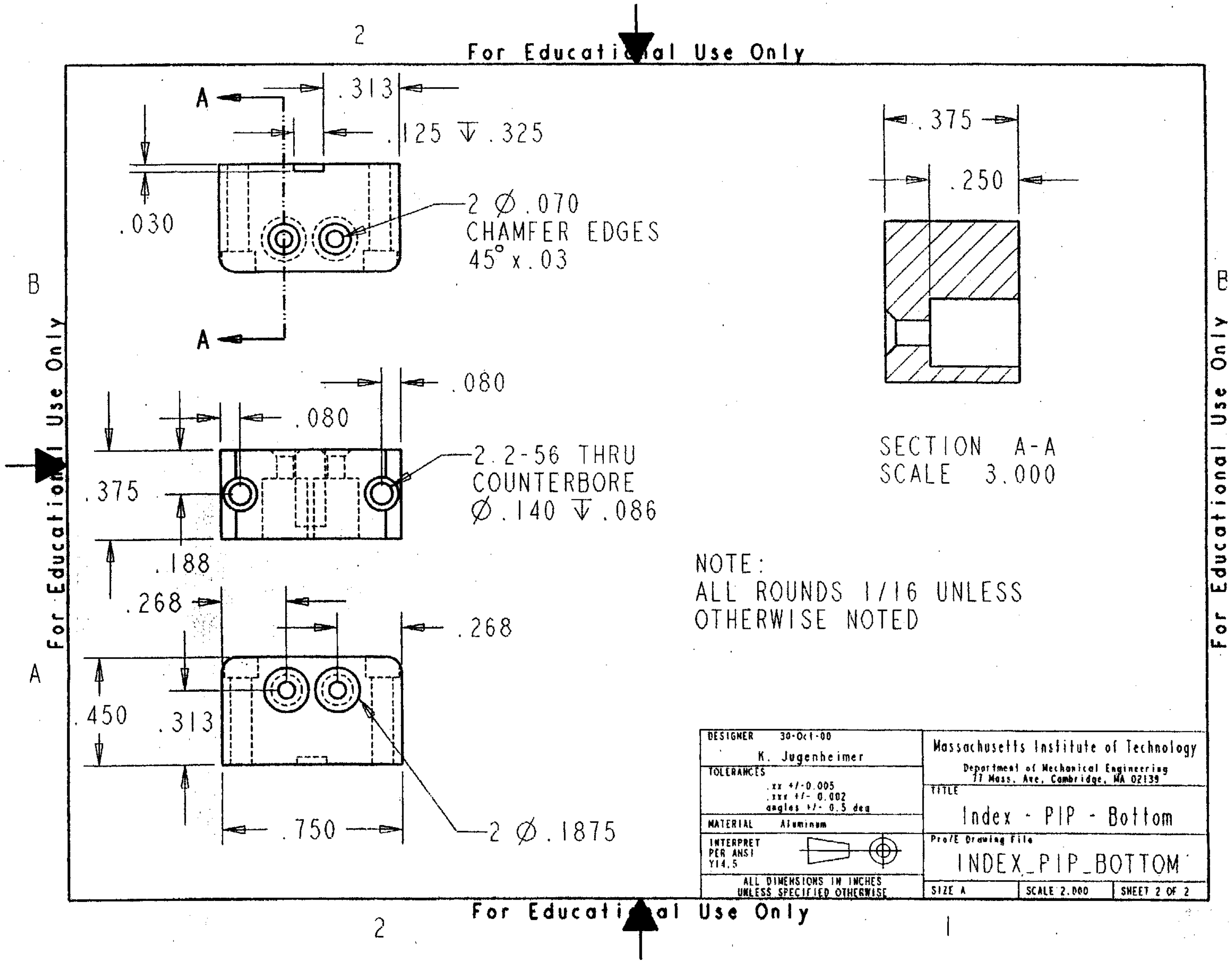
ISOMETRIC VIEW

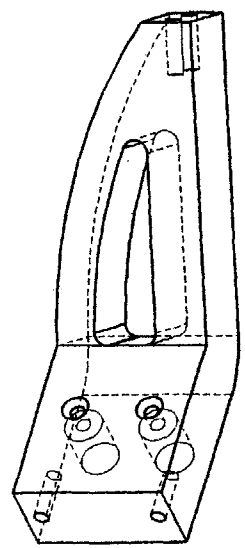
A

DESIGNER 05-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - PIP - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File INDEX_PIP_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 3.000 · SHEET 1 OF 2

2

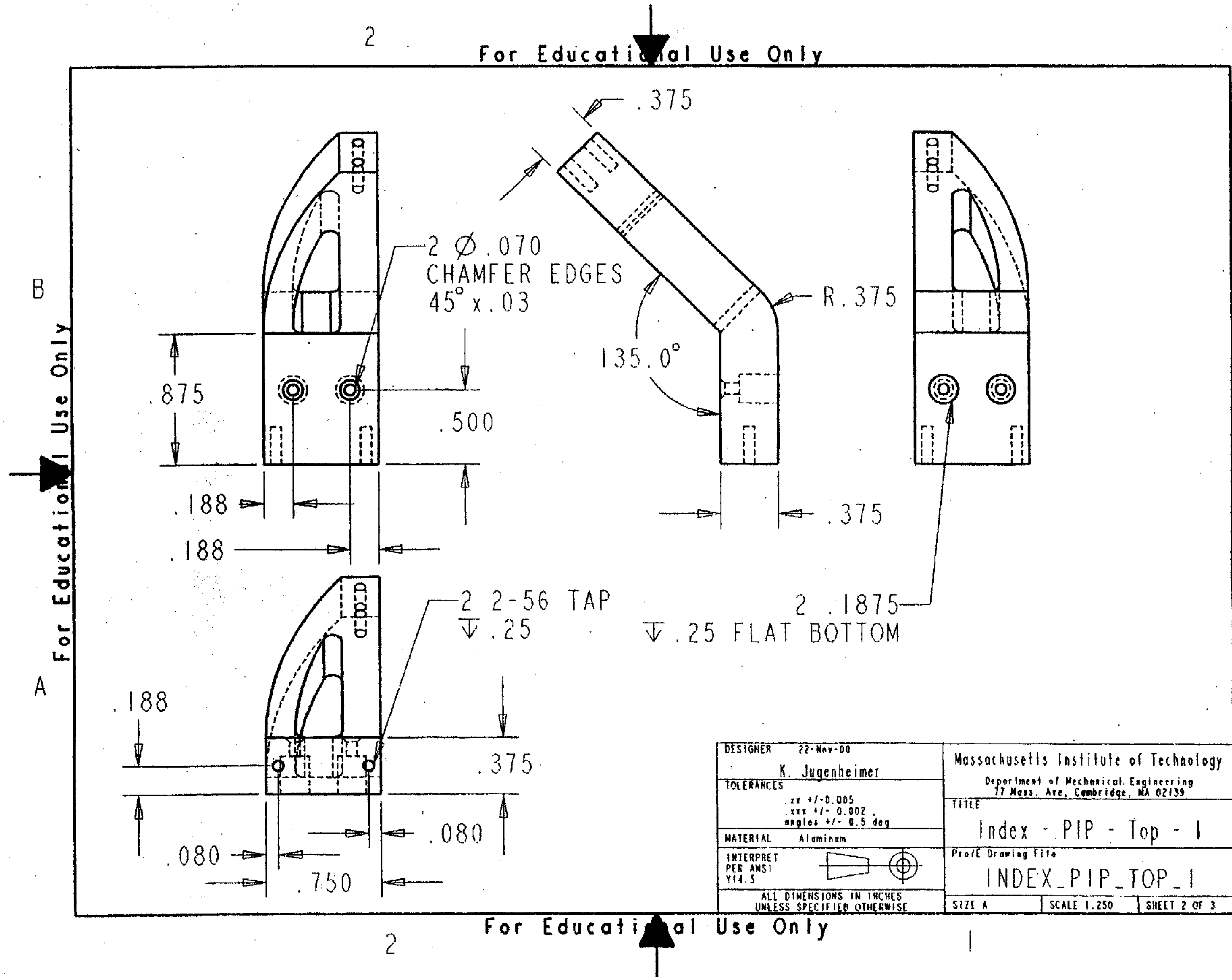
1

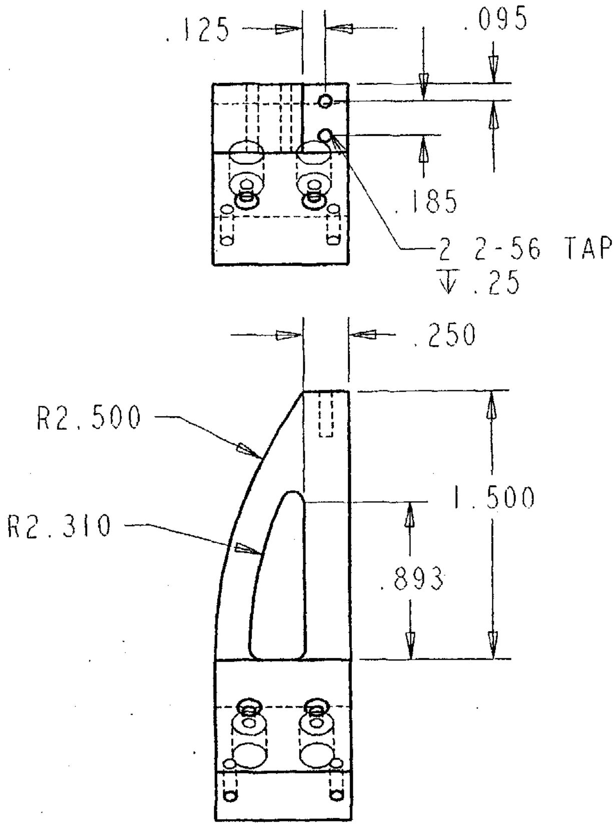

For Educational Use Only
.313
.125 ⊽ .325
.030
2 Ø .070
CHAMFER EDGES
45° x .03
A
A
.375
.250
SECTION A-A
SCALE 3.000
.080
.080
.375
2. 2-56 THRU
COUNTERBORE
Ø .140 ⊽ .086
.188
.268
.268
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
.450
.313
.750
2 Ø .1875
DESIGNER 30-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Index - PIP - Bottom
Pro/E Drawing File
INDEX_PIP_BOTTOM
SIZE A
SCALE 2.000
SHEET 2 OF 2
For Educational Use Only



ISOMETRIC VIEW

DESIGNER 22-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - PIP - Top - 1
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File INDEX_PIP_TOP_1
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 1.500 · SHEET 1 OF 3

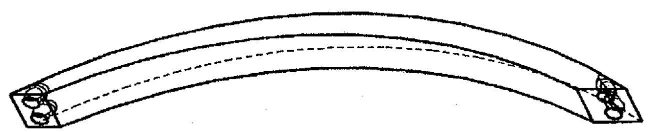

For Educational Use Only
2
B
A
.375
2 Ø.070
CHAMFER EDGES
45° x .03
R.375
135.0°
.875
.500
.188
.188
.375
2 2-56 TAP
⊽ .25
2 .1875
⊽ .25 FLAT BOTTOM
.188
.375
.080
.080
.750
DESIGNER 22-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Index - PIP - Top - 1
Pro/E Drawing File
INDEX_PIP_TOP_1
SIZE A
SCALE 1.250
SHEET 2 OF 3
1



NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED

DESIGNER 22-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - PIP - Top - 1
MATERIAL Aluminum	Pro/E Drawing File INDEX_PIP_TOP_1
INTERPRET PER ANSI Y14.5	
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.250 | SHEET 3 OF 3

For Educational Use Only



ISOMETRIC VIEW

DESIGNER 22-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, NA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - PIP - Top - 2
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File INDEX_PIP_TOP_2
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 1.000 · SHEET 1 OF 2

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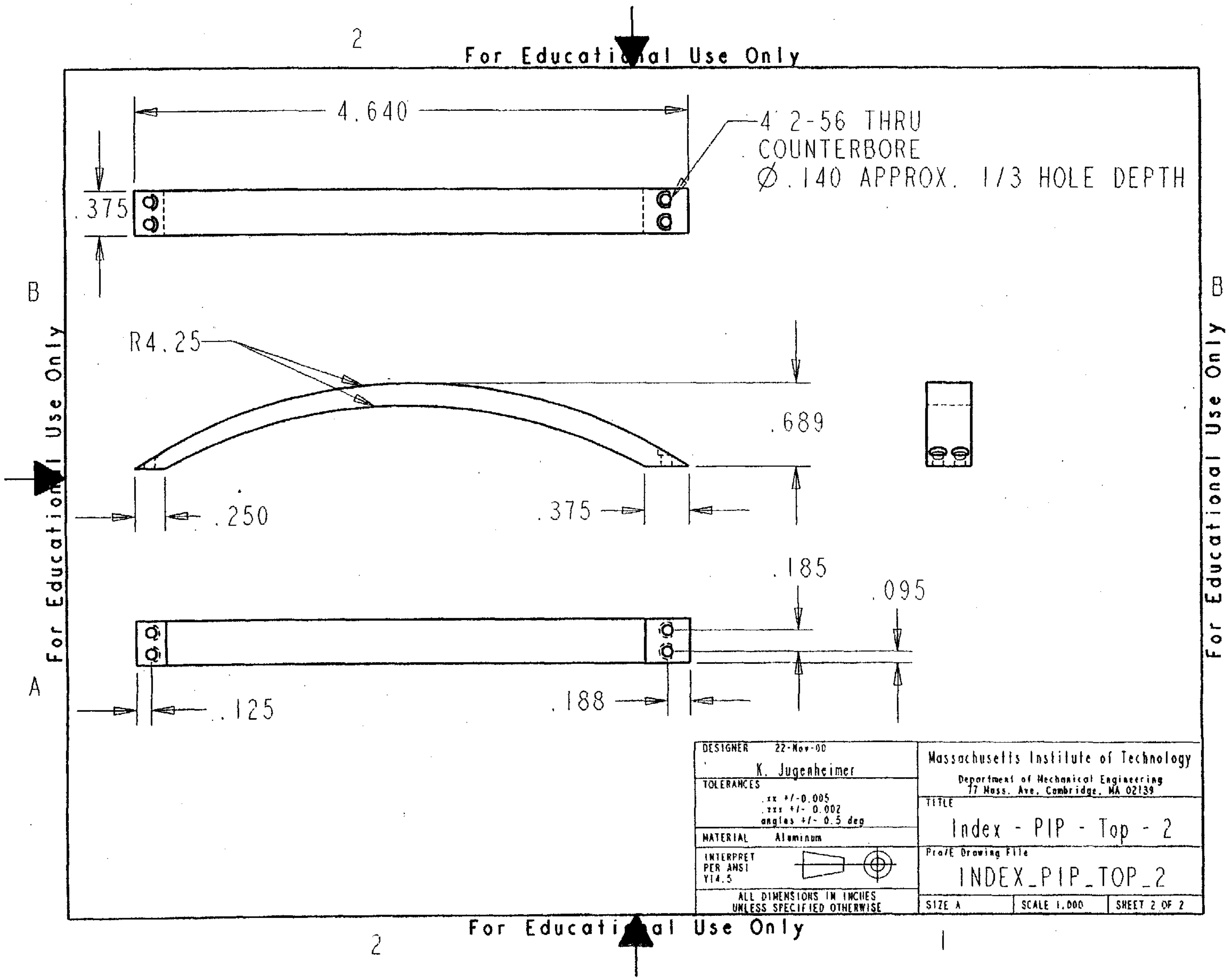
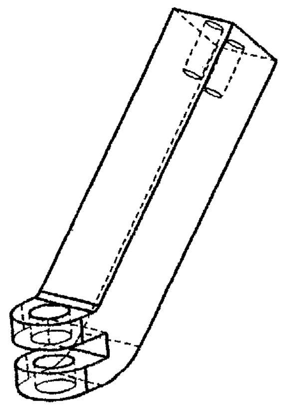
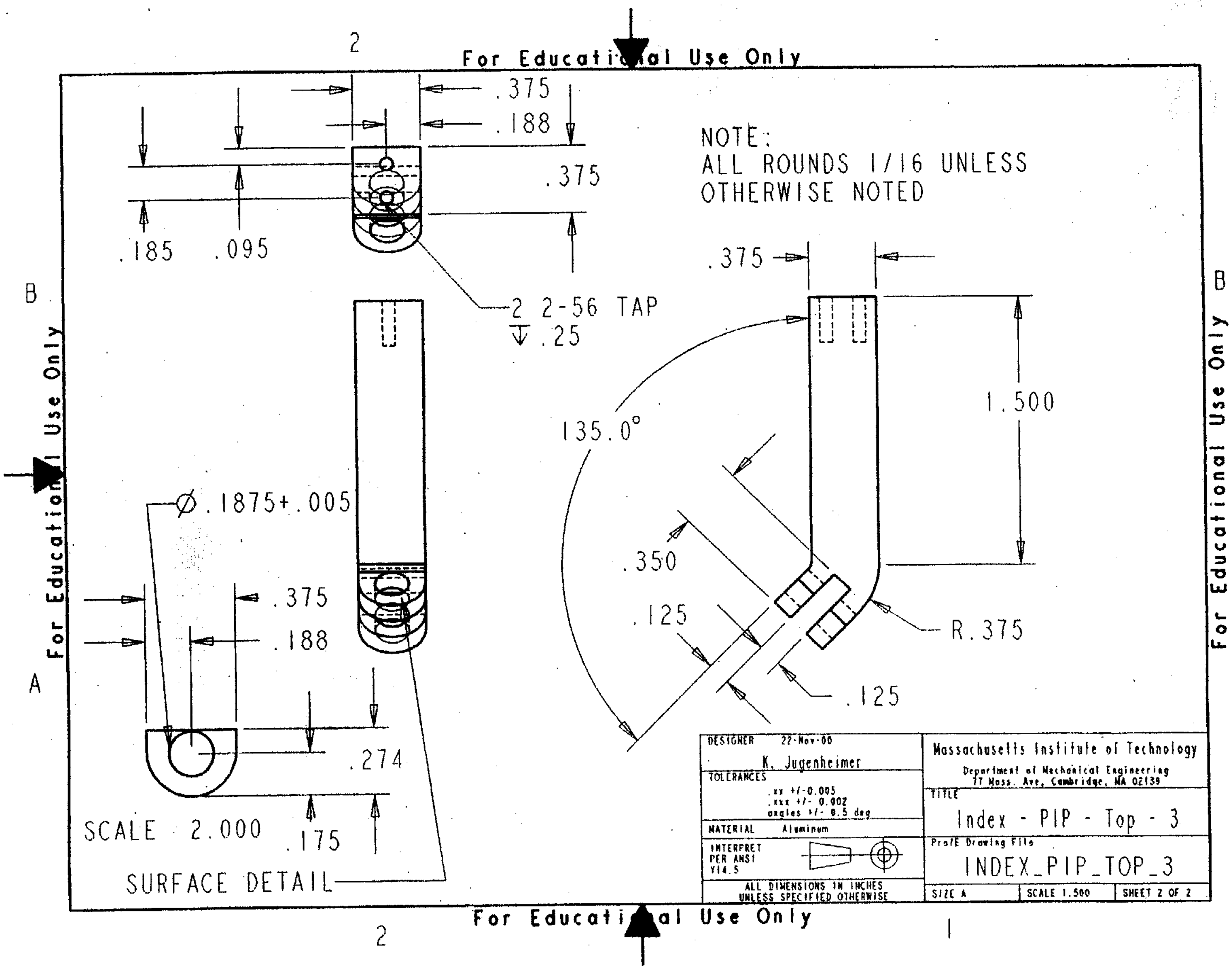
For Educational Use Only
For Educational Use Only


For Educational Use Only
4.640
4 2-56 THRU
COUNTERBORE
Ø.140 APPROX. 1/3 HOLE DEPTH
.375
R4.25
.689
.250
.375
.185
.095
.125
.188
DESIGNER 22-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Index - PIP - Top - 2
Pro/E Drawing File
INDEX_PIP_TOP_2
SIZE A
SCALE 1.000
SHEET 2 OF 2



ISOMETRIC VIEW

DESIGNER 22-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Index - PIP - Top - 3
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File INDEX_PIP_TOP_3
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 1.500 / SHEET 1 OF 2


For Educational Use Only
.375
.188
.375
.185
.095
2 2-56 TAP
.25
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
.375
1.500
135.0°
.350
.125
R.375
.125
Ø.1875+.005
.375
.188
.274
.175
SCALE 2.000
SURFACE DETAIL
DESIGNER 22-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Index - PIP - Top - 3
Pro/E Drawing File
INDEX_PIP_TOP_3
SIZE A
SCALE 1.500
SHEET 2 OF 2

11-7-00

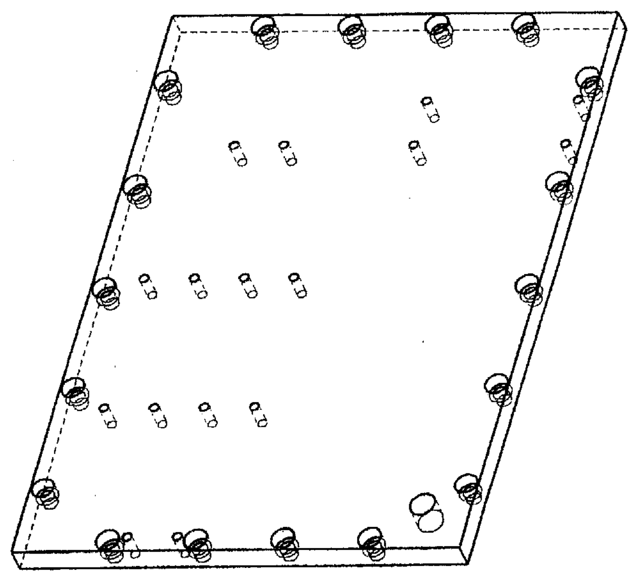
2

For Educational Use Only

B

For Educational Use Only

A



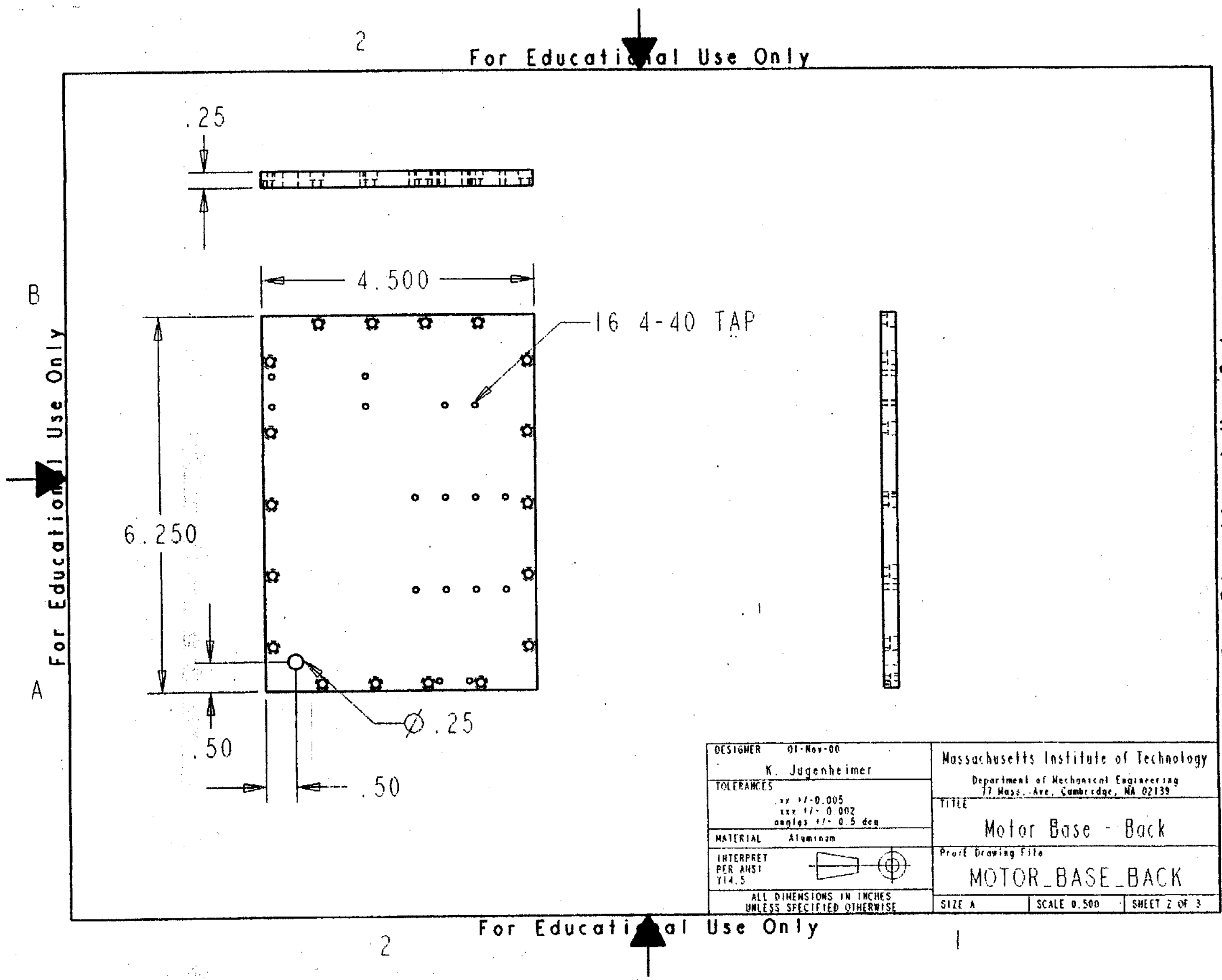
ISOMETRIC VIEW

DESIGNER 01-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Back
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_BASE_BACK
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.750 | SHEET 1 OF 3

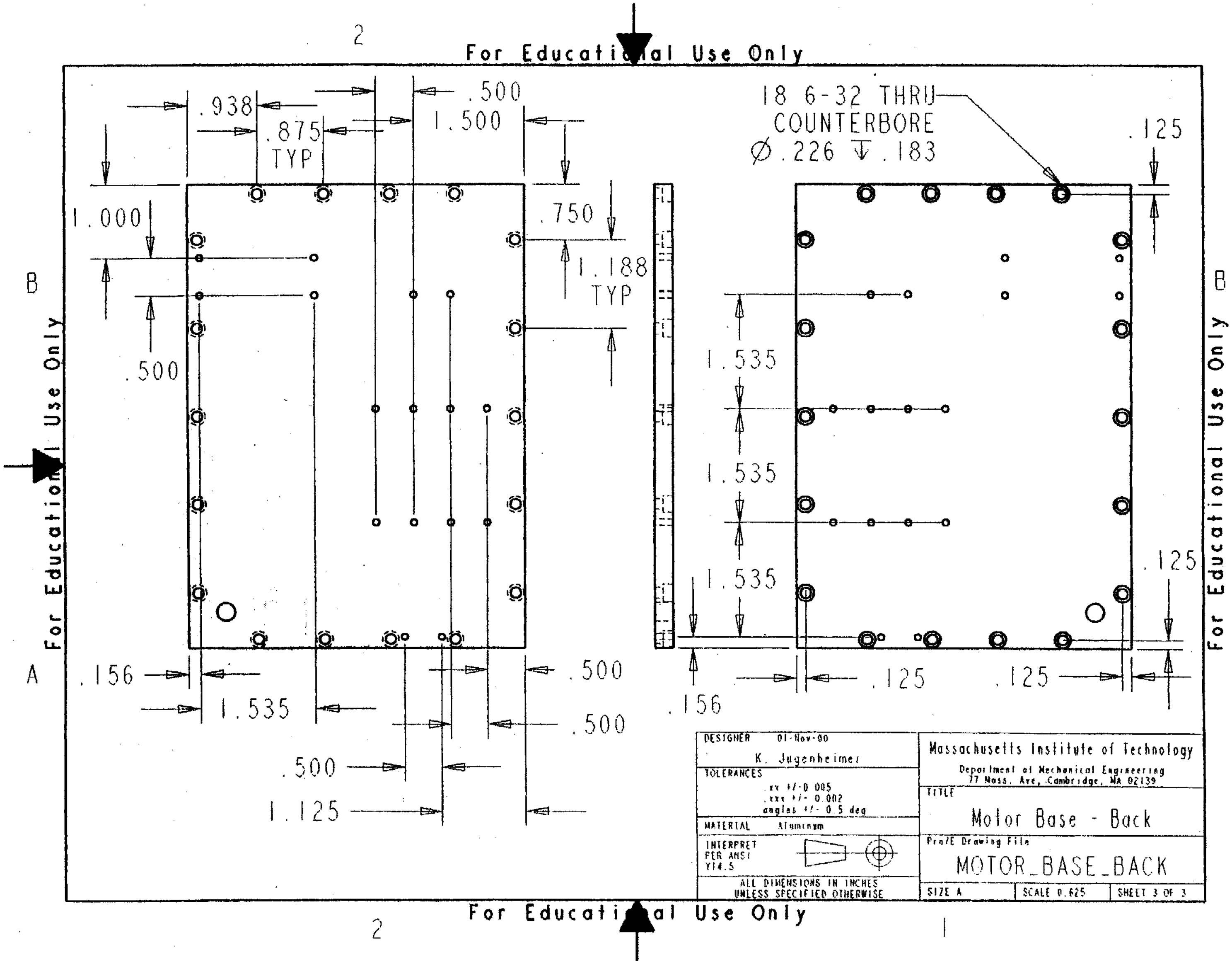
For Educational Use Only

2

1



For Educational Use Only
2
.25
4.500
B
A
16 4-40 TAP
6.250
.50
Ø.25
.50
DESIGNER 01-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Back
ProE Drawing File
MOTOR_BASE_BACK
SIZE A
SCALE 0.500
SHEET 2 OF 3
1


For Educational Use Only
18 6-32 THRU
COUNTERBORE
Ø.226 ↧ .183
.938
.875
TYP
.500
1.500
1.000
.750
1.188
TYP
.500
.125
1.535
1.535
1.535
.125
.156
1.535
.500
.500
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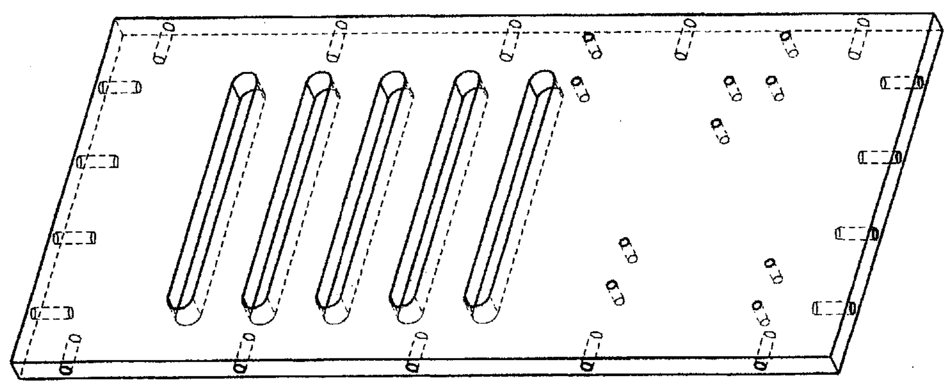
1.125
.156
.125
.125
B
A
2
1
DESIGNER 01-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Back
Pro/E Drawing File
MOTOR_BASE_BACK
SIZE A
SCALE 0.625
SHEET 3 OF 3

11-7-00

For Educational Use Only



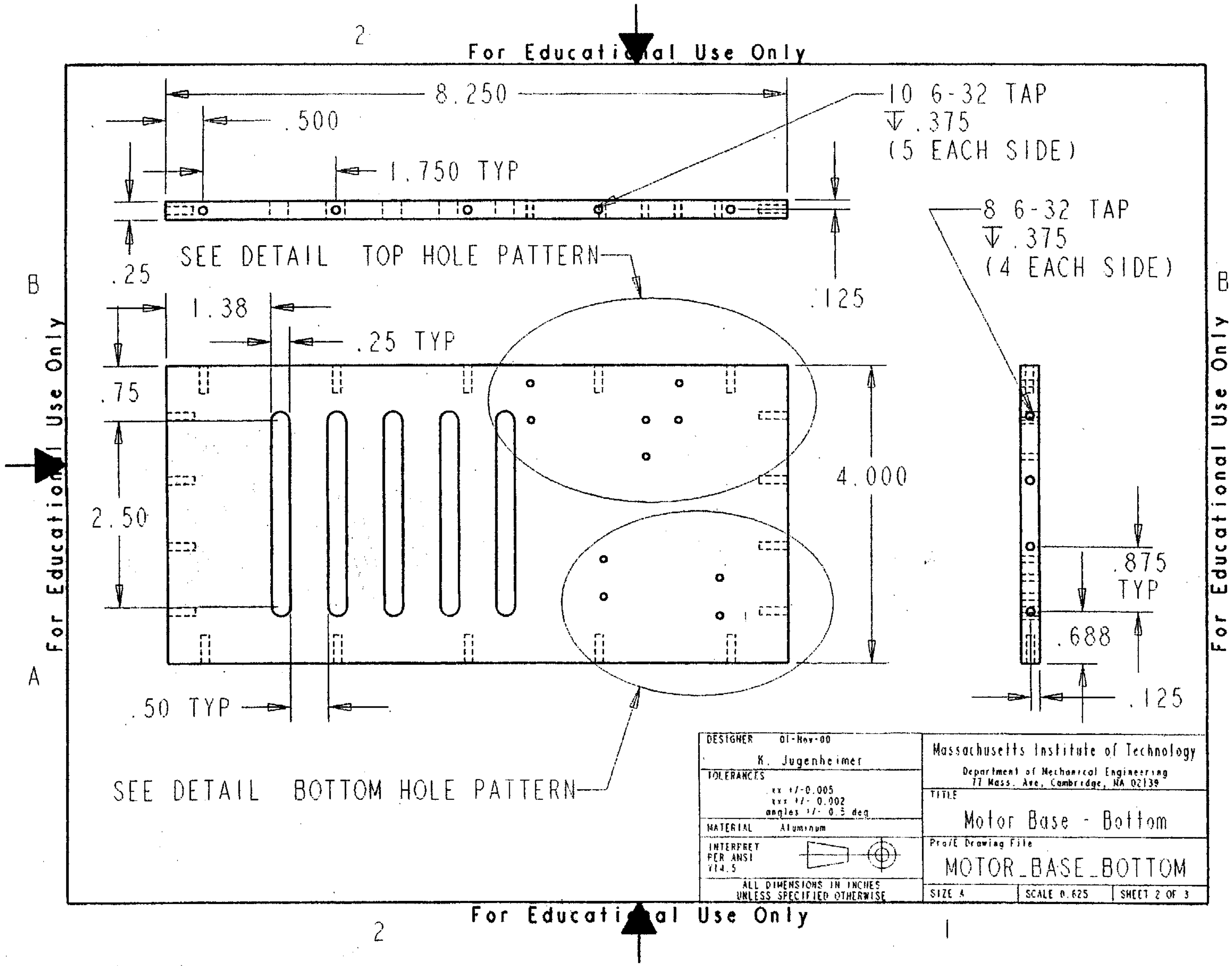
ISOMETRIC VIEW

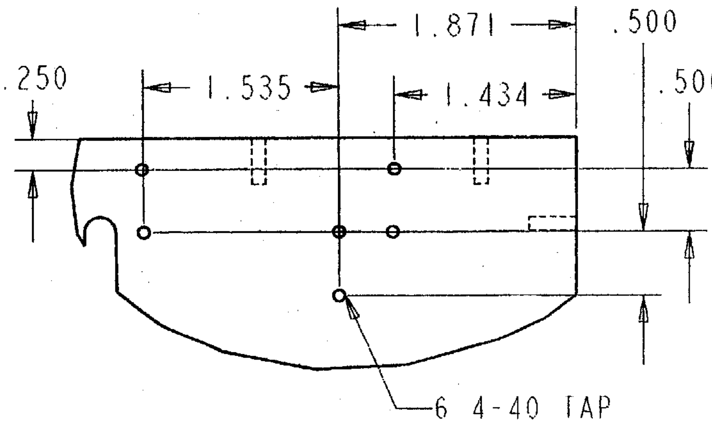
DESIGNER 01-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES xx +/-0.005 xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_BASE_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A	SCALE 0.750	SHEET 1 OF 3

For Educational Use Only

For Educational Use Only

For Educational Use Only


For Educational Use Only
8.250
.500
1.750 TYP
10 6-32 TAP
.375
(5 EACH SIDE)
.25
.125
SEE DETAIL TOP HOLE PATTERN
8 6-32 TAP
.375
(4 EACH SIDE)
1.38
.25 TYP
.75
2.50
4.000
.875
TYP
.688
.125
.50 TYP
SEE DETAIL BOTTOM HOLE PATTERN
DESIGNER 01-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Bottom
Pro/E Drawing File
MOTOR_BASE_BOTTOM
SIZE A
SCALE 0.625
SHEET 2 OF 3



DETAIL TOP HOLE PATTERN
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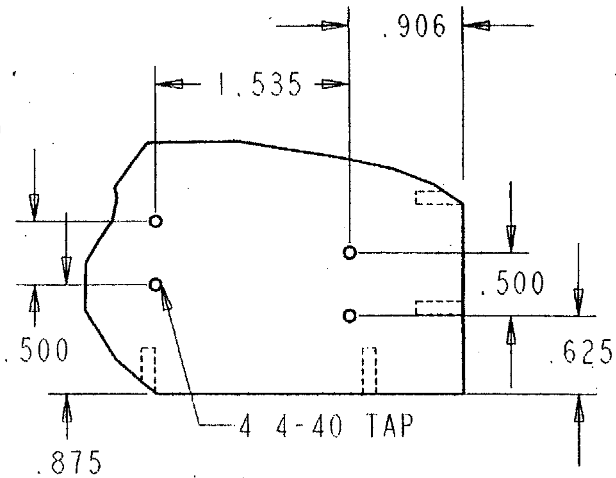
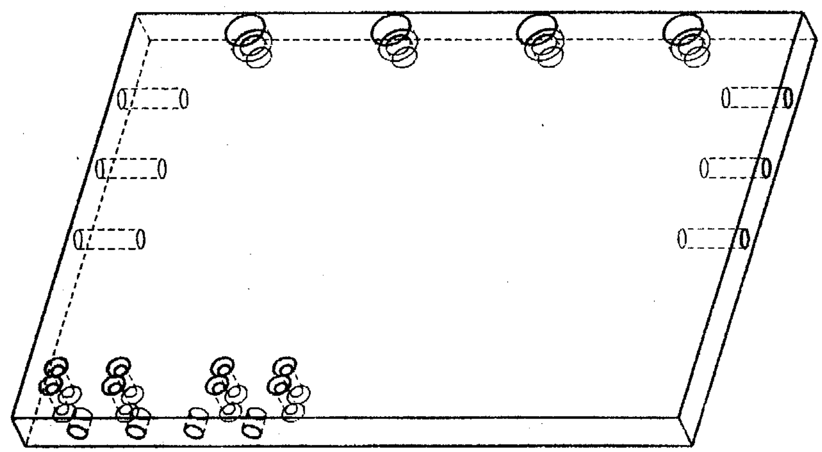


DETAIL BOTTOM HOLE PATTERN
SCALE 0.875

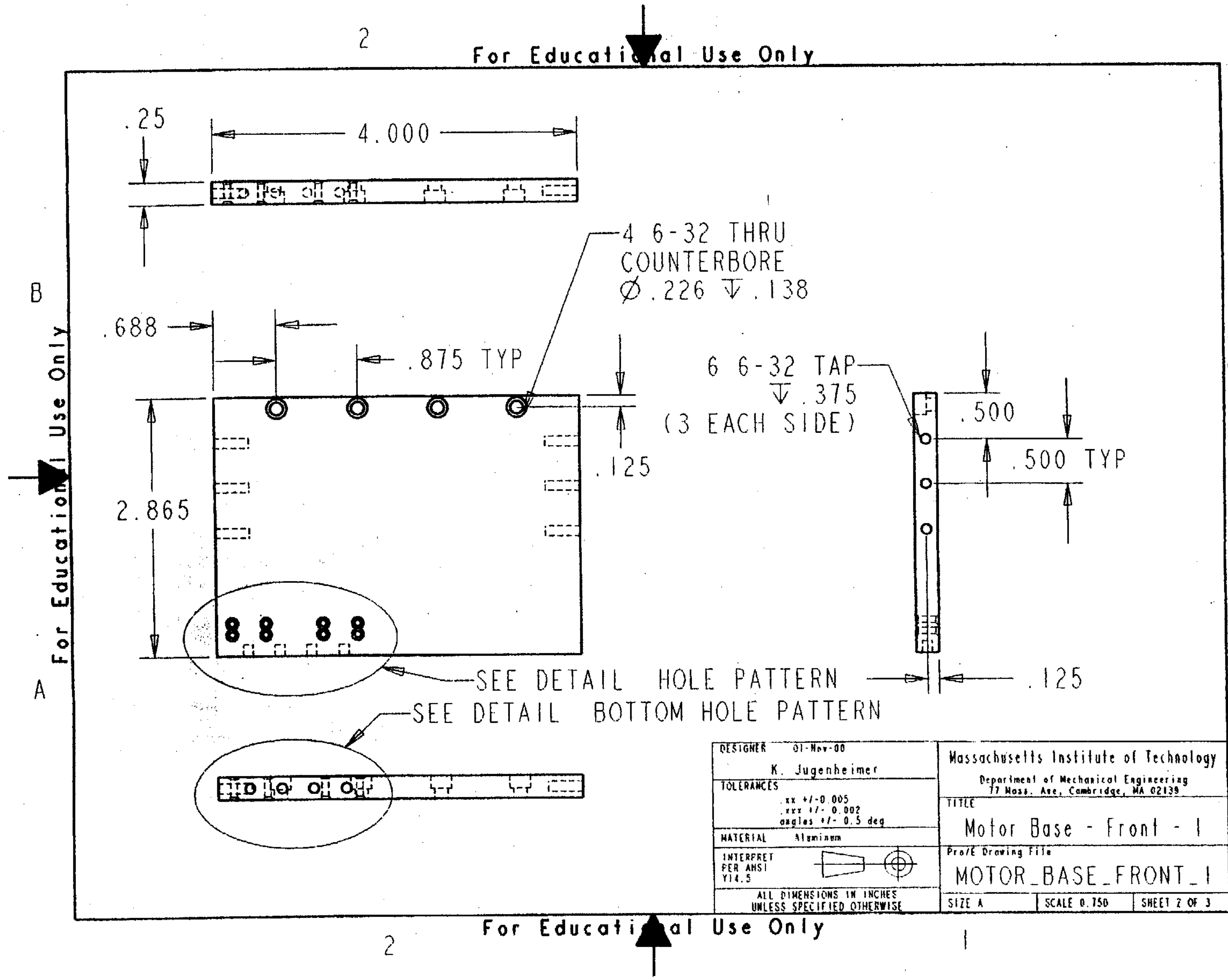
DESIGNER 01-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_BASE_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A	SCALE 0.625	SHEET 3 OF 3

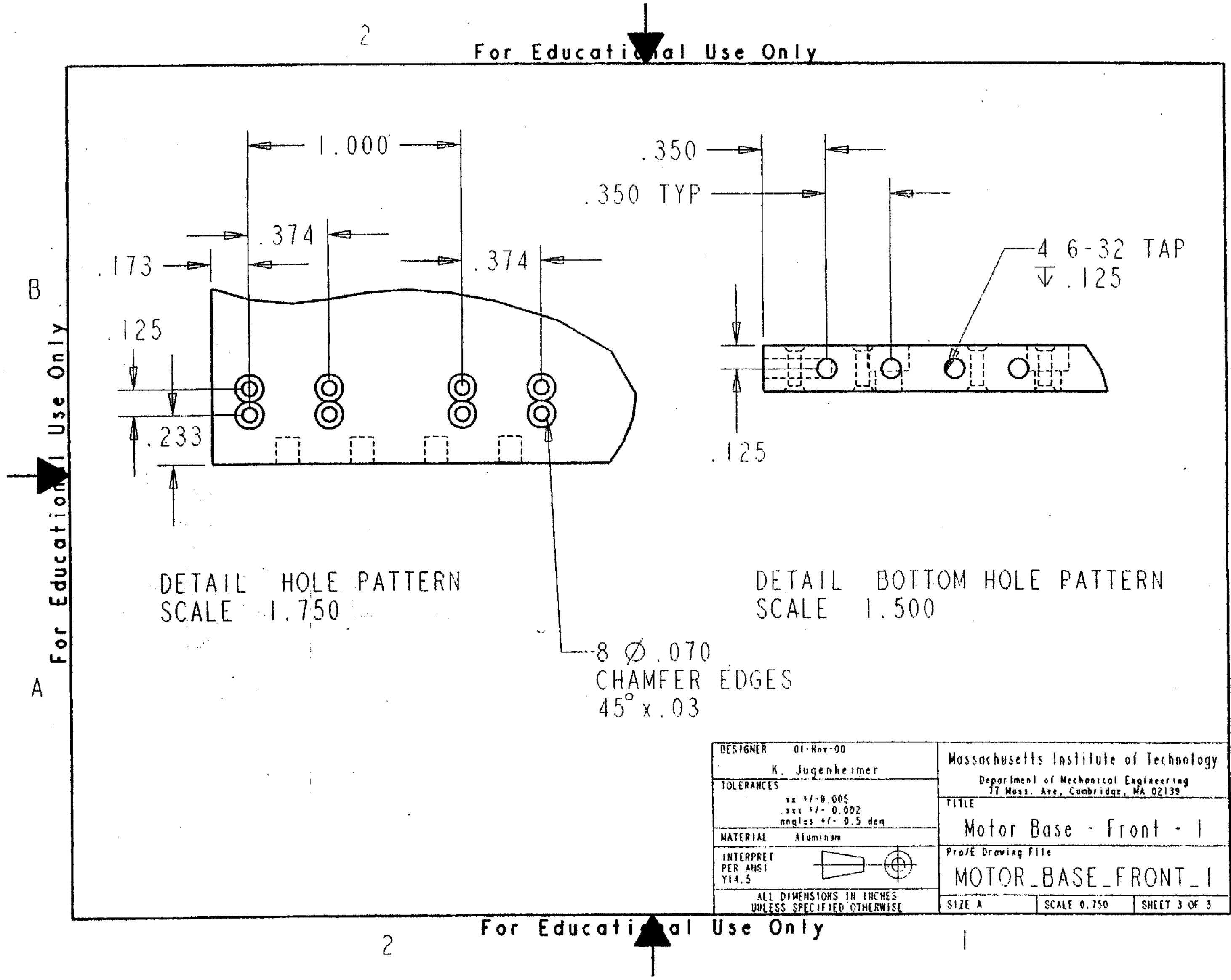
11-7-00



ISOMETRIC VIEW

DESIGNER 01-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES xx +/- 0.005 xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Front - 1
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_BASE_FRONT_1
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.250 | SHEET 1 OF 3


For Educational Use Only
.25
4.000
4 6-32 THRU
COUNTERBORE
Ø.226 ↧.138
.688
.875 TYP
6 6-32 TAP
↧.375
(3 EACH SIDE)
.500
.500 TYP
.125
2.865
SEE DETAIL HOLE PATTERN
SEE DETAIL BOTTOM HOLE PATTERN
.125
DESIGNER 01-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Front - 1
Pro/E Drawing File
MOTOR_BASE_FRONT_1
SIZE A
SCALE 0.750
SHEET 2 OF 3


For Educational Use Only
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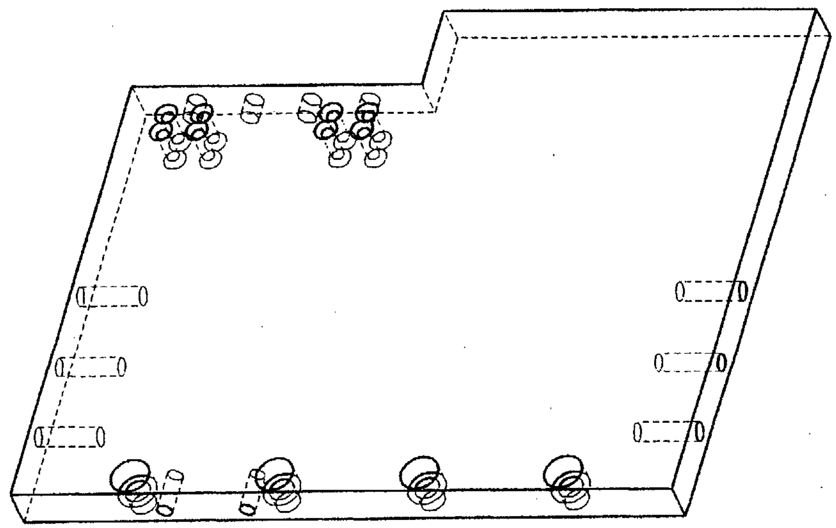
.173
.374
.125
.233
4 6-32 TAP
↧ .125
.125
DETAIL HOLE PATTERN
SCALE 1.750
DETAIL BOTTOM HOLE PATTERN
SCALE 1.500
8 Ø .070
CHAMFER EDGES
45° x .03
DESIGNER 01-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Front - 1
Pro/E Drawing File
MOTOR_BASE_FRONT_1
SIZE A
SCALE 0.750
SHEET 3 OF 3

11-7-00

2

For Educational Use Only

B



ISOMETRIC VIEW

A

DESIGNER 01-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Front - 2
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_BASE_FRONT_2
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.250 | SHEET 1 OF 3

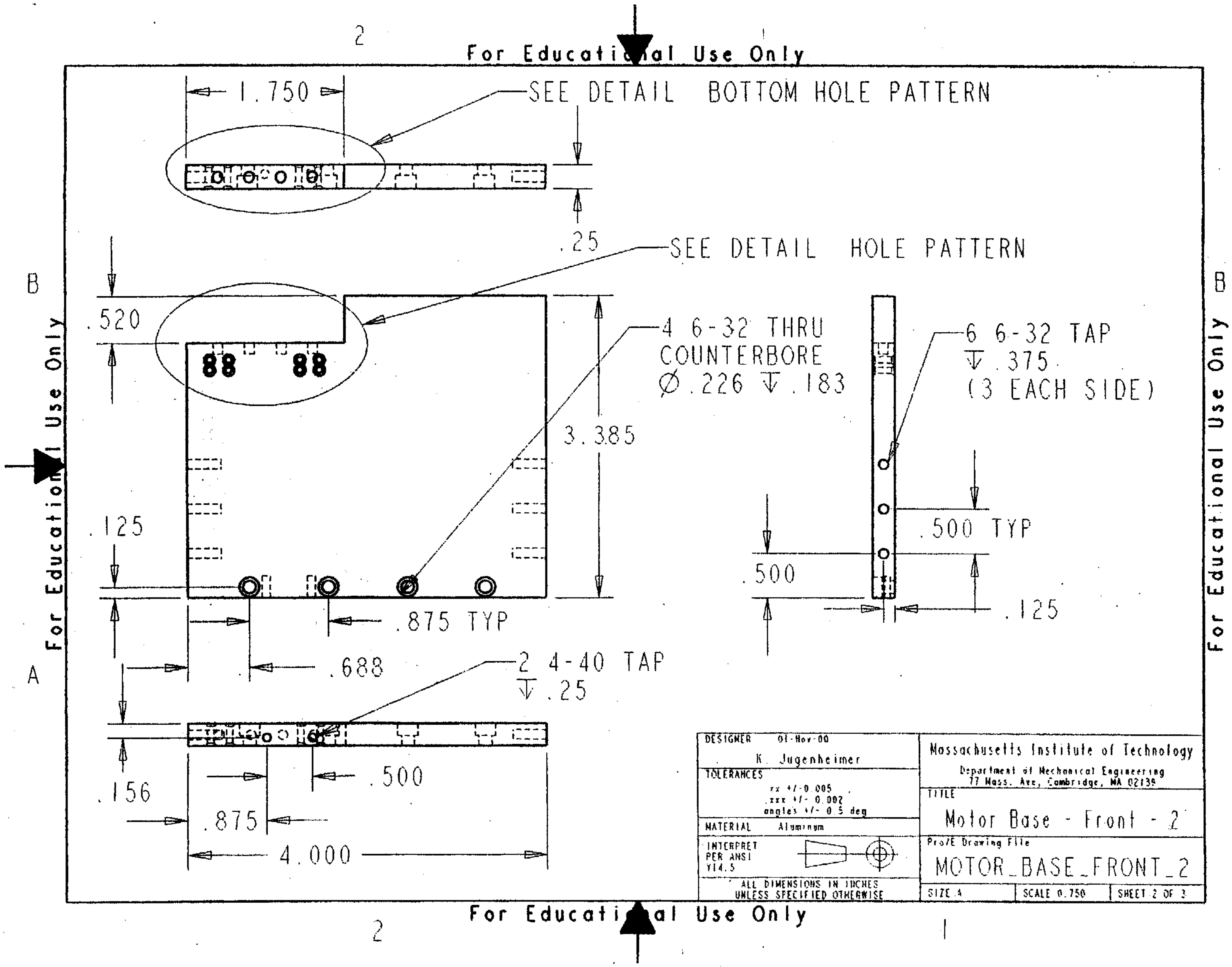
For Educational Use Only

For Educational Use Only

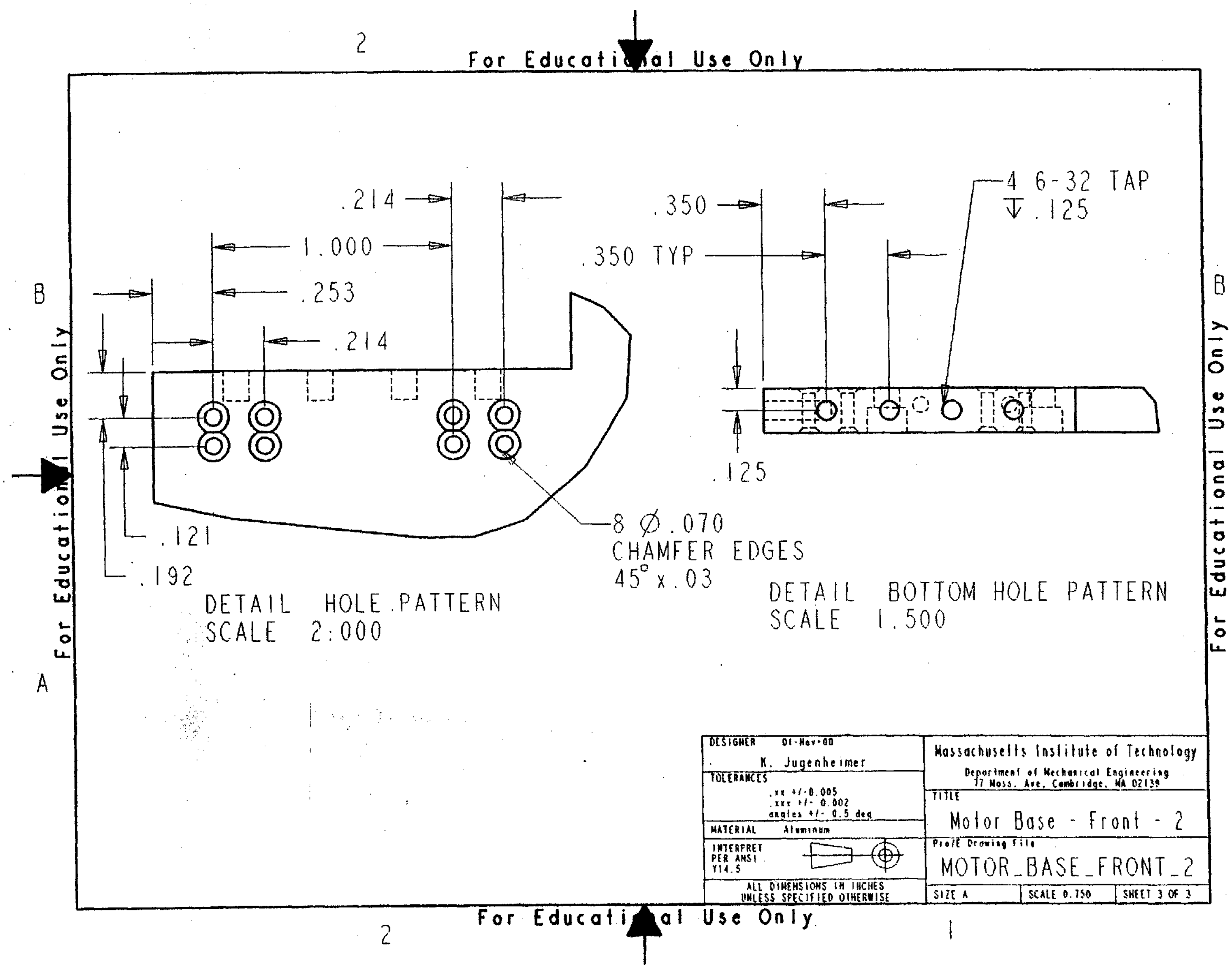
For Educational Use Only

2

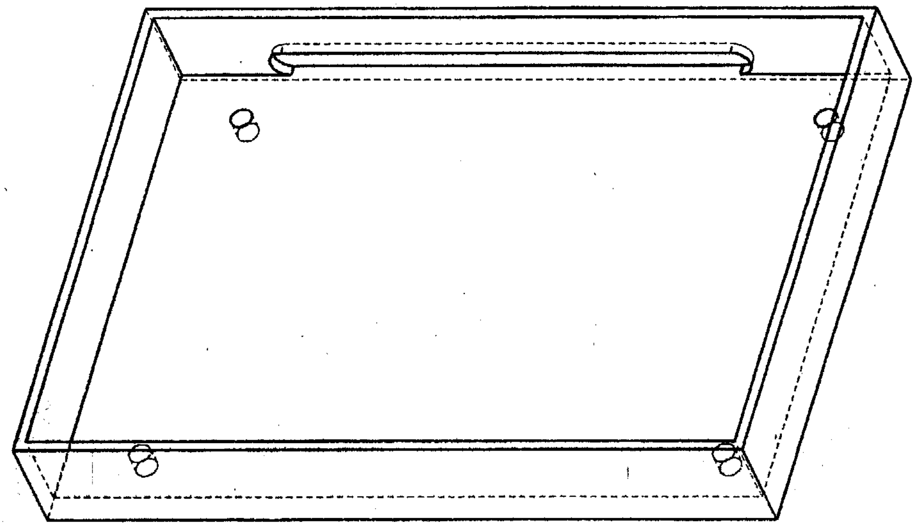
1



For Educational Use Only
1.750
SEE DETAIL BOTTOM HOLE PATTERN
.25
SEE DETAIL HOLE PATTERN
.520
4 6-32 THRU
COUNTERBORE
∅.226 ↧.183
3.385
6 6-32 TAP
↧.375
(3 EACH SIDE)
.125
.500 TYP
.500
.125
.875 TYP
.688
2 4-40 TAP
↧.25
.156
.500
.875
4.000
DESIGNER 01-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Front - 2
Pro/E Drawing File
MOTOR_BASE_FRONT_2
SIZE A
SCALE 0.750
SHEET 2 OF 3


For Educational Use Only
.214
1.000
.253
.214
.121
.192
8 Ø .070
CHAMFER EDGES
45° x .03
DETAIL HOLE PATTERN
SCALE 2:000
.350
.350 TYP
4 6-32 TAP
↧ .125
.125
DETAIL BOTTOM HOLE PATTERN
SCALE 1.500
DESIGNER 01-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Motor Base - Front - 2
ProE Drawing File
MOTOR_BASE_FRONT_2
SIZE A
SCALE 0.750
SHEET 3 OF 3

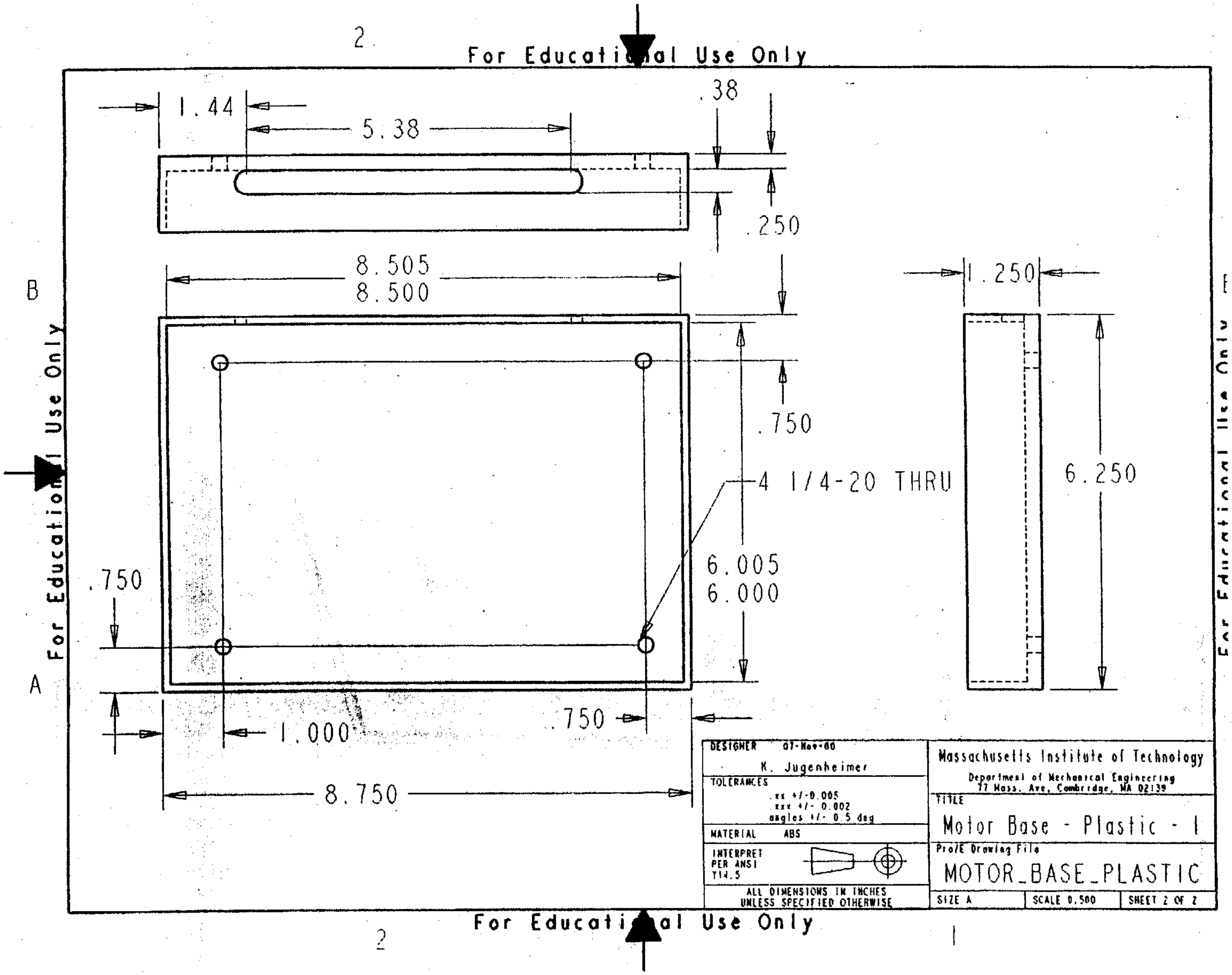
For Educational Use Only

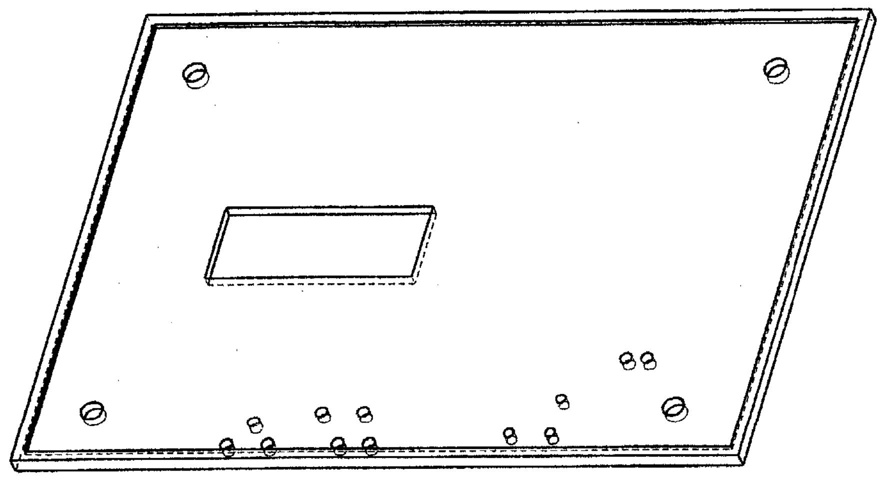


ISOMETRIC VIEW

DESIGNER 07-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Plastic - 1
MATERIAL ABS	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_BASE_PLASTIC
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.625 | SHEET 1 OF 2

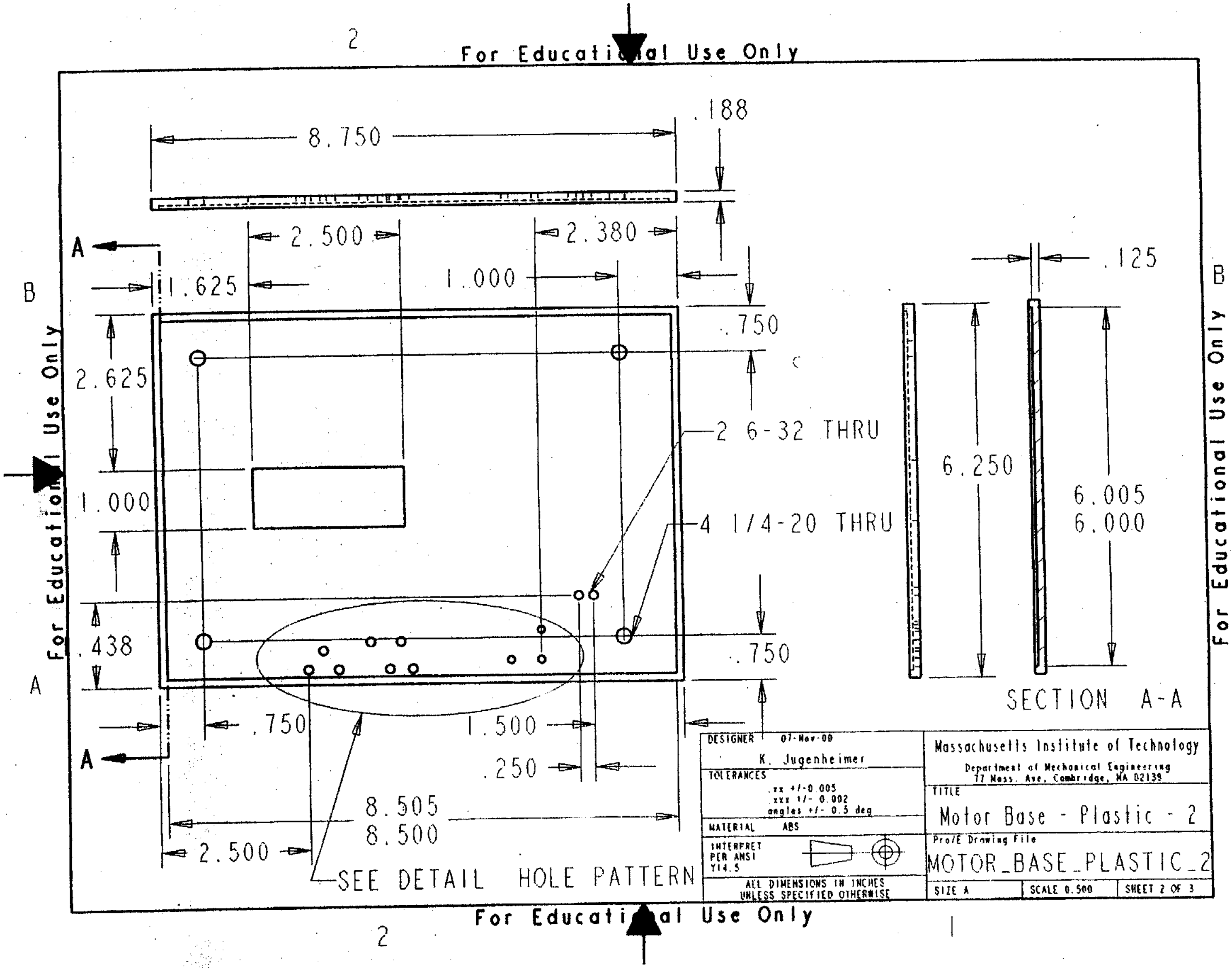
For Educational Use Only

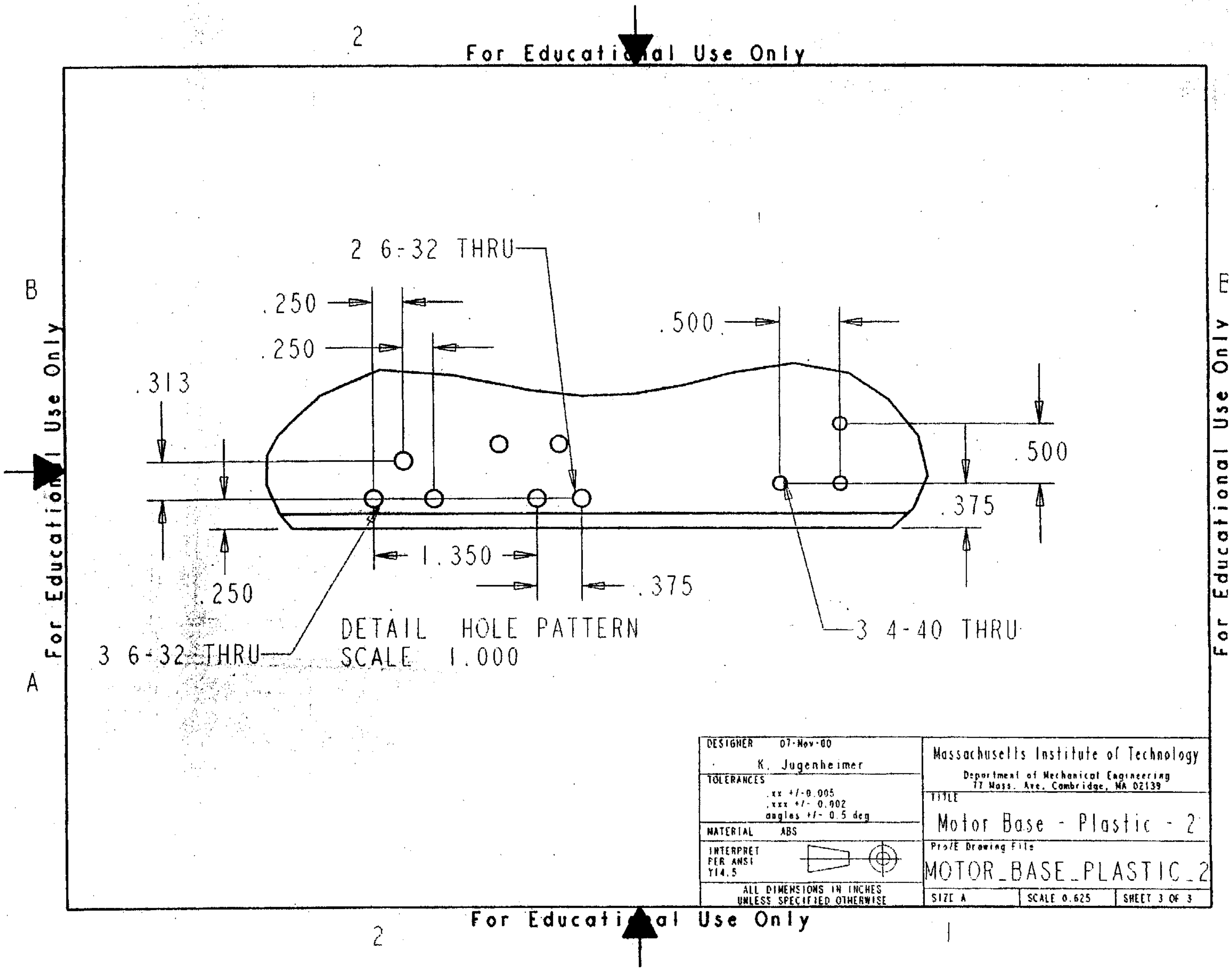

For Educational Use Only
1.44
5.38
.38
.250
8.505
8.500
1.250
.750
4 1/4-20 THRU
6.250
6.005
6.000
.750
1.000
.750
8.750
B
A
2
1
DESIGNER 07-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL ABS
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Plastic - I
Pro/E Drawing File
MOTOR_BASE_PLASTIC
SIZE A
SCALE 0.500
SHEET 2 OF 2



ISOMETRIC VIEW

DESIGNER 07-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Plastic - 2
MATERIAL ABS	Pro/E Drawing File MOTOR_BASE_PLASTIC_2
INTERPRET PER ANSI Y14.5	
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.625 | SHEET 1 OF 3

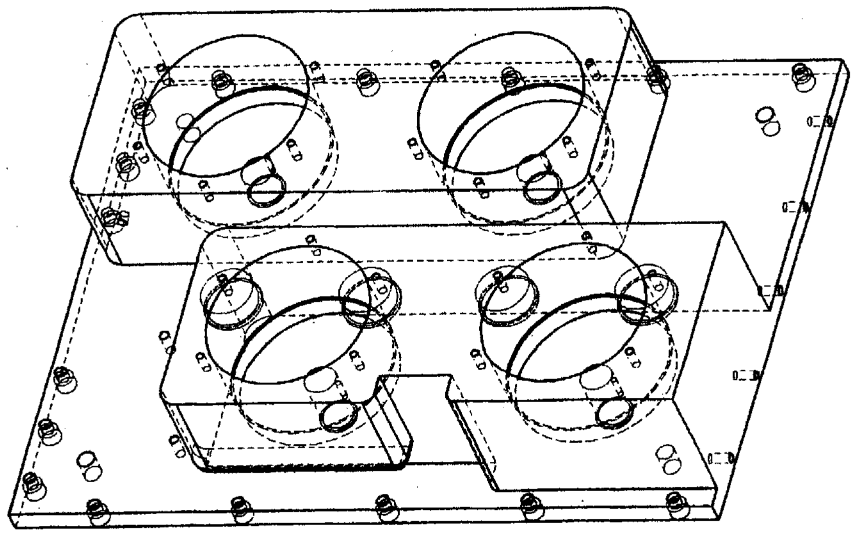

For Educational Use Only
8.750
.188
2.500
2.380
1.625
1.000
.125
.750
2.625
2 6-32 THRU
4 1/4-20 THRU
6.250
6.005
6.000
1.000
.438
.750
SECTION A-A
.750
1.500
.250
8.505
8.500
2.500
SEE DETAIL HOLE PATTERN
A
B
DESIGNER 07-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL ABS
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Plastic - 2
Pro/E Drawing File
MOTOR_BASE_PLASTIC_2
SIZE A
SCALE 0.500
SHEET 2 OF 3


For Educational Use Only
2 6-32 THRU
.250
.250
.313
.500
.500
.375
1.350
.375
.250
DETAIL HOLE PATTERN
SCALE 1.000
3 6-32 THRU
3 4-40 THRU
DESIGNER 07-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL ABS
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Motor Base - Plastic - 2
Pro/E Drawing File
MOTOR_BASE_PLASTIC_2
SIZE A
SCALE 0.625
SHEET 3 OF 3

11-7-00

2

B



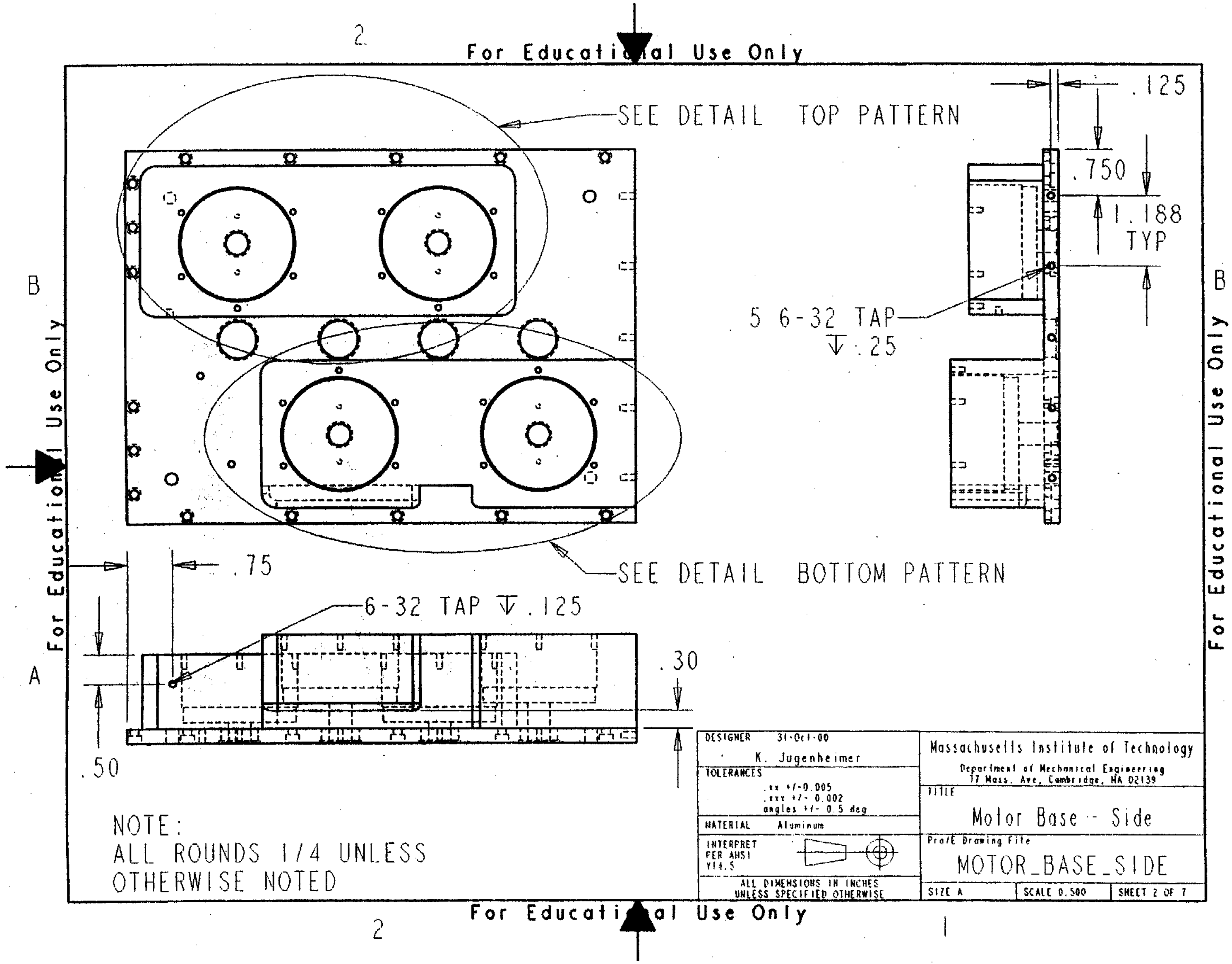
ISOMETRIC VIEW

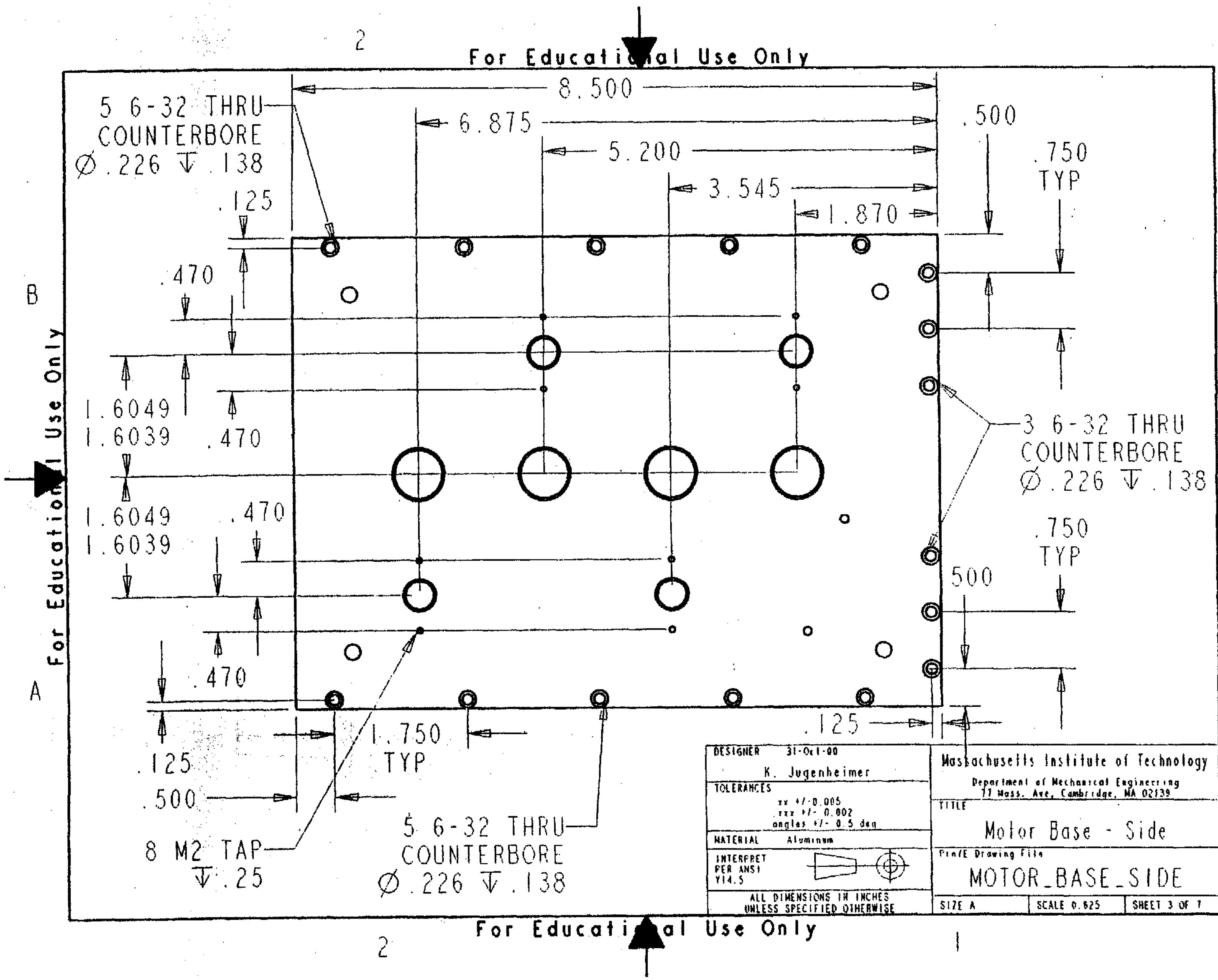
A

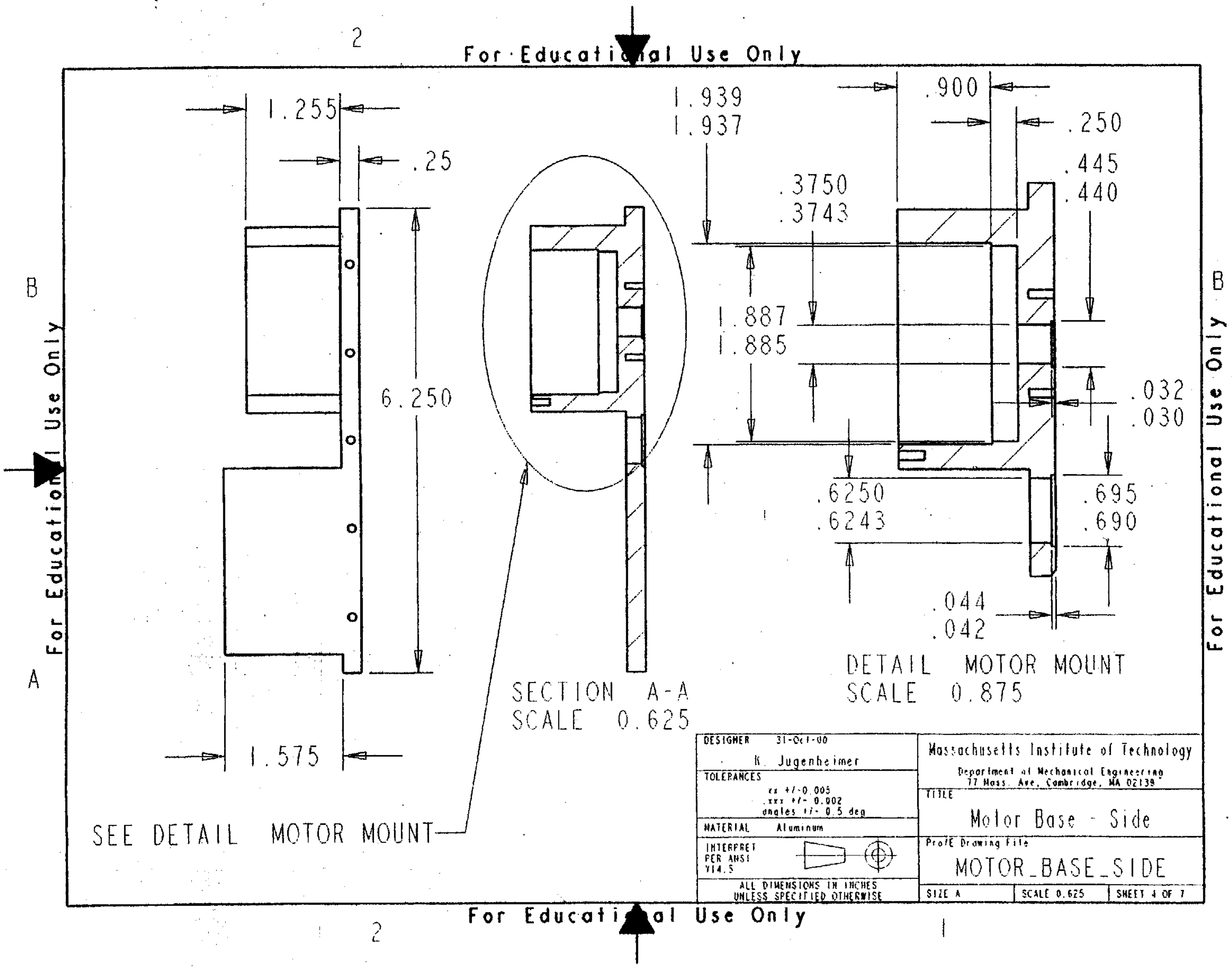
DESIGNER 03-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Side
MATERIAL Aluminum	Pro/E Drawing File MOTOR_BASE_SIDE
INTERPRET PER ANSI Y14.5	
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.525 | SHEET 1 OF 7

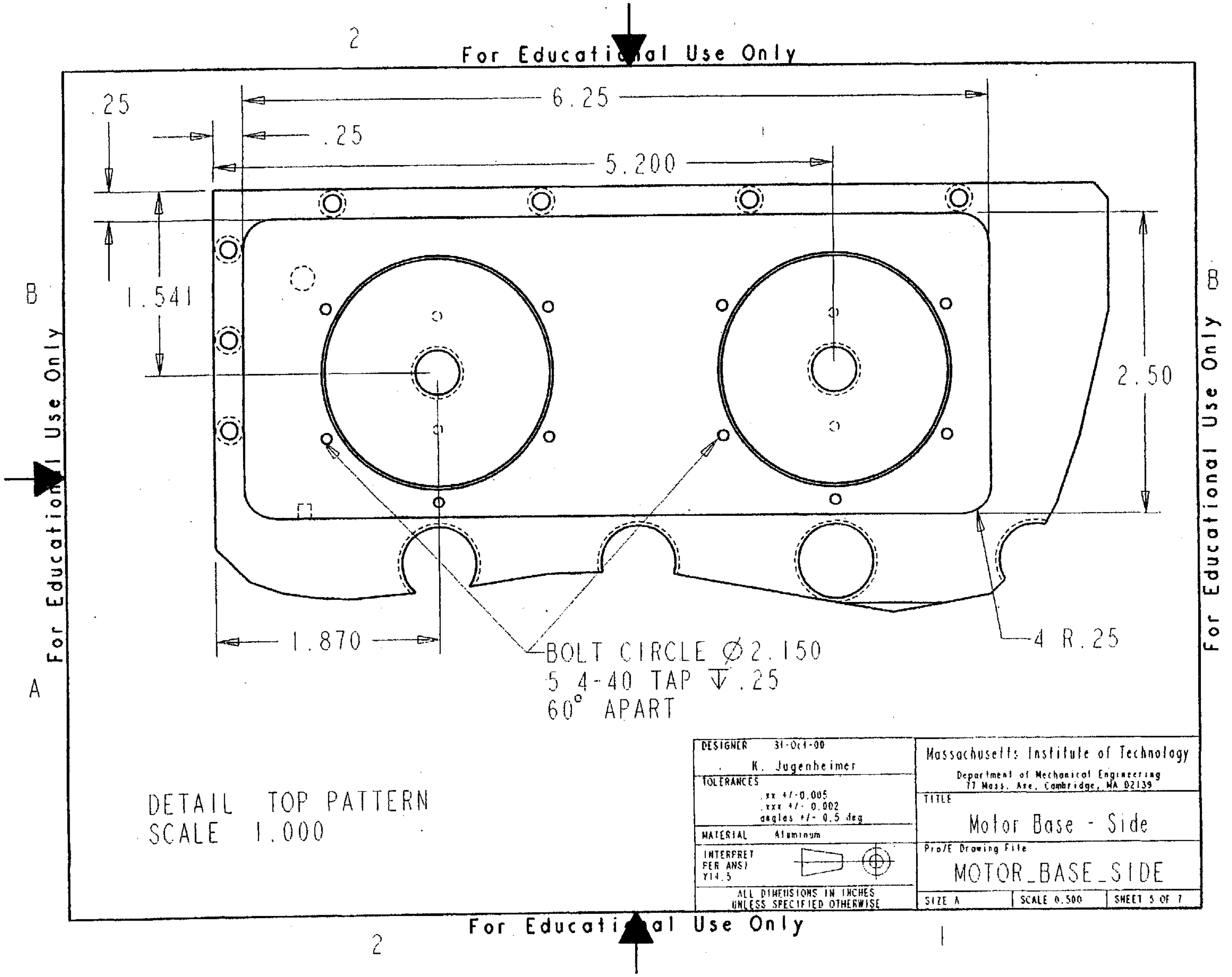
2 1

For Educational Use Only

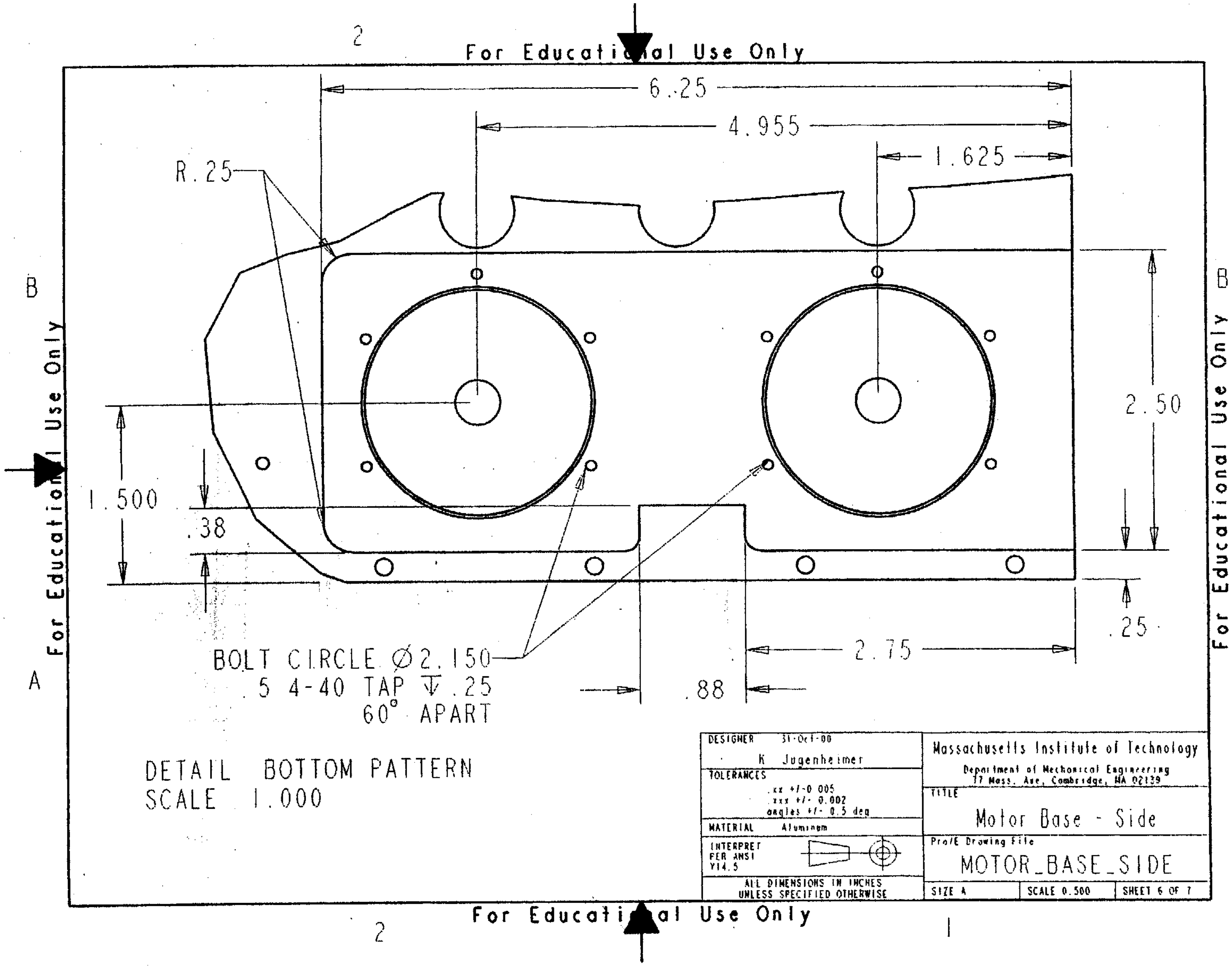

For Educational Use Only
SEE DETAIL TOP PATTERN
SEE DETAIL BOTTOM PATTERN
.125
.750
1.188
TYP
5 6-32 TAP
↧ .25
.75
6-32 TAP ↧ .125
.30
.50
NOTE:
ALL ROUNDS 1/4 UNLESS
OTHERWISE NOTED
DESIGNER 31-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side
Pro/E Drawing File
MOTOR_BASE_SIDE
SIZE A
SCALE 0.500
SHEET 2 OF 7
A
B
1
2

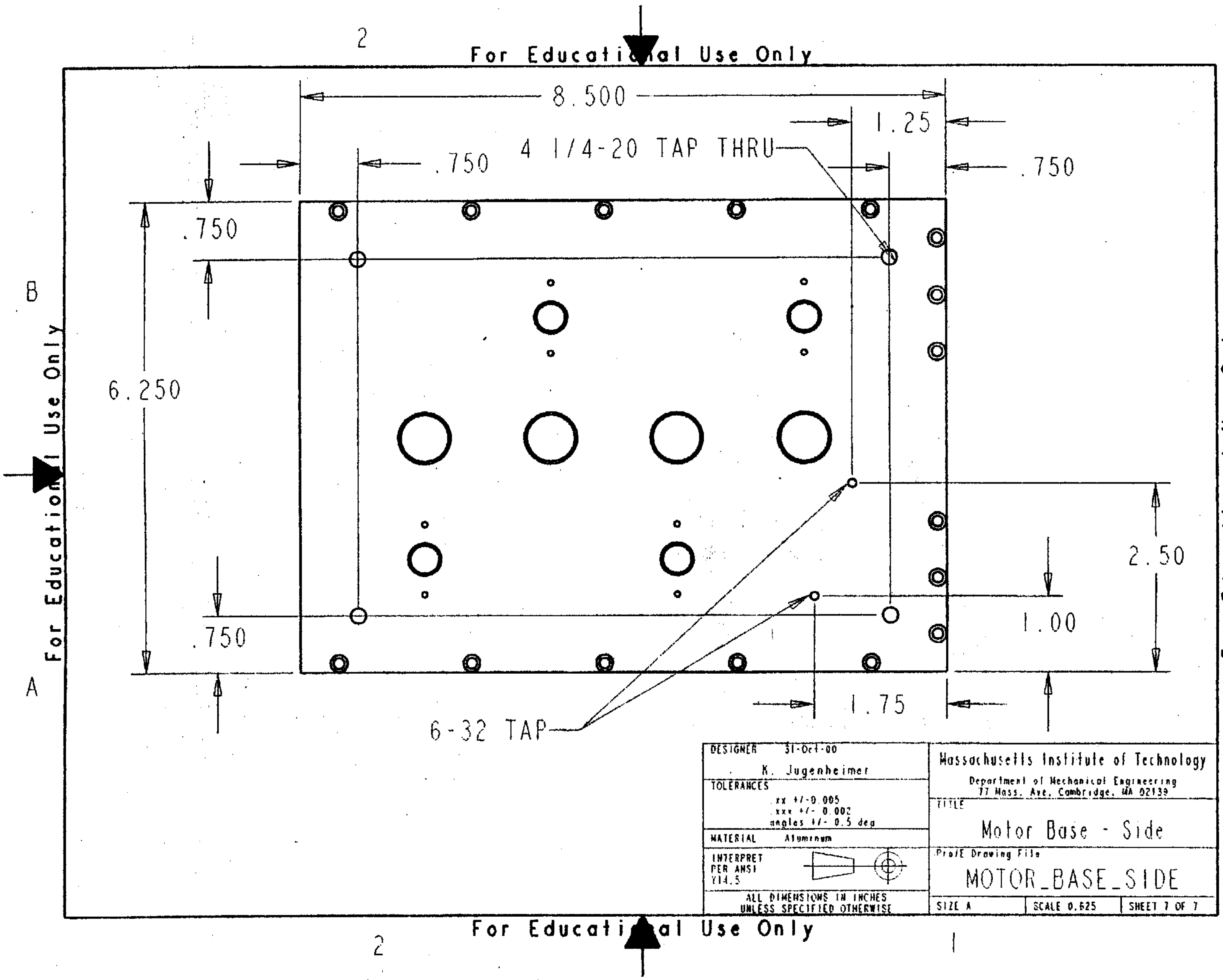

For Educational Use Only
8.500
6.875
5.200
3.545
1.870
.500
.750 TYP
.125
.470
1.6049
1.6039
5 6-32 THRU COUNTERBORE ∅.226 ↧.138
3 6-32 THRU COUNTERBORE ∅.226 ↧.138
8 M2 TAP ↧.25
1.750 TYP
.500
DESIGNER 31-Oct-00
K. Jugenheimer
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side
Pro/E Drawing File
MOTOR_BASE_SIDE
SIZE A
SCALE 0.625
SHEET 3 OF 7

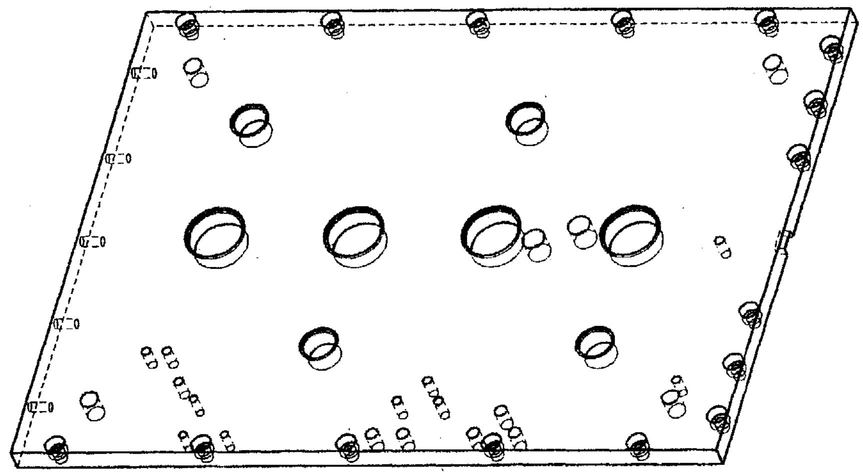

For Educational Use Only
1.255
.25
6.250
1.575
SEE DETAIL MOTOR MOUNT
SECTION A-A
SCALE 0.625
1.939
1.937
.3750
.3743
1.887
1.885
.6250
.6243
.900
.250
.445
.440
.032
.030
.695
.690
.044
.042
DETAIL MOTOR MOUNT
SCALE 0.875
DESIGNER 31-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side
Pro/E Drawing File
MOTOR_BASE_SIDE
SIZE A
SCALE 0.625
SHEET 4 OF 7



2
For Educational Use Only
6.25
.25
.25
5.200
1.541
2.50
1.870
BOLT CIRCLE ⌀2.150
5 4-40 TAP ↧.25
60° APART
4 R.25
B
A
For Educational Use Only
For Educational Use Only
DETAIL TOP PATTERN
SCALE 1.000
DESIGNER 31-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side
Pro/E Drawing File
MOTOR_BASE_SIDE
SIZE A
SCALE 0.500
SHEET 5 OF 7
For Educational Use Only
2
1


For Educational Use Only
6.25
4.955
1.625
R.25
2.50
1.500
.38
.25
2.75
.88
BOLT CIRCLE Ø2.150
.5 4-40 TAP ↧ .25
60° APART
DETAIL BOTTOM PATTERN
SCALE 1.000
DESIGNER 31-Oct-00
K Jugenheimer
TOLERANCES
.xx +/-0 005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side
Pro/E Drawing File
MOTOR_BASE_SIDE
SIZE A
SCALE 0.500
SHEET 6 OF 7

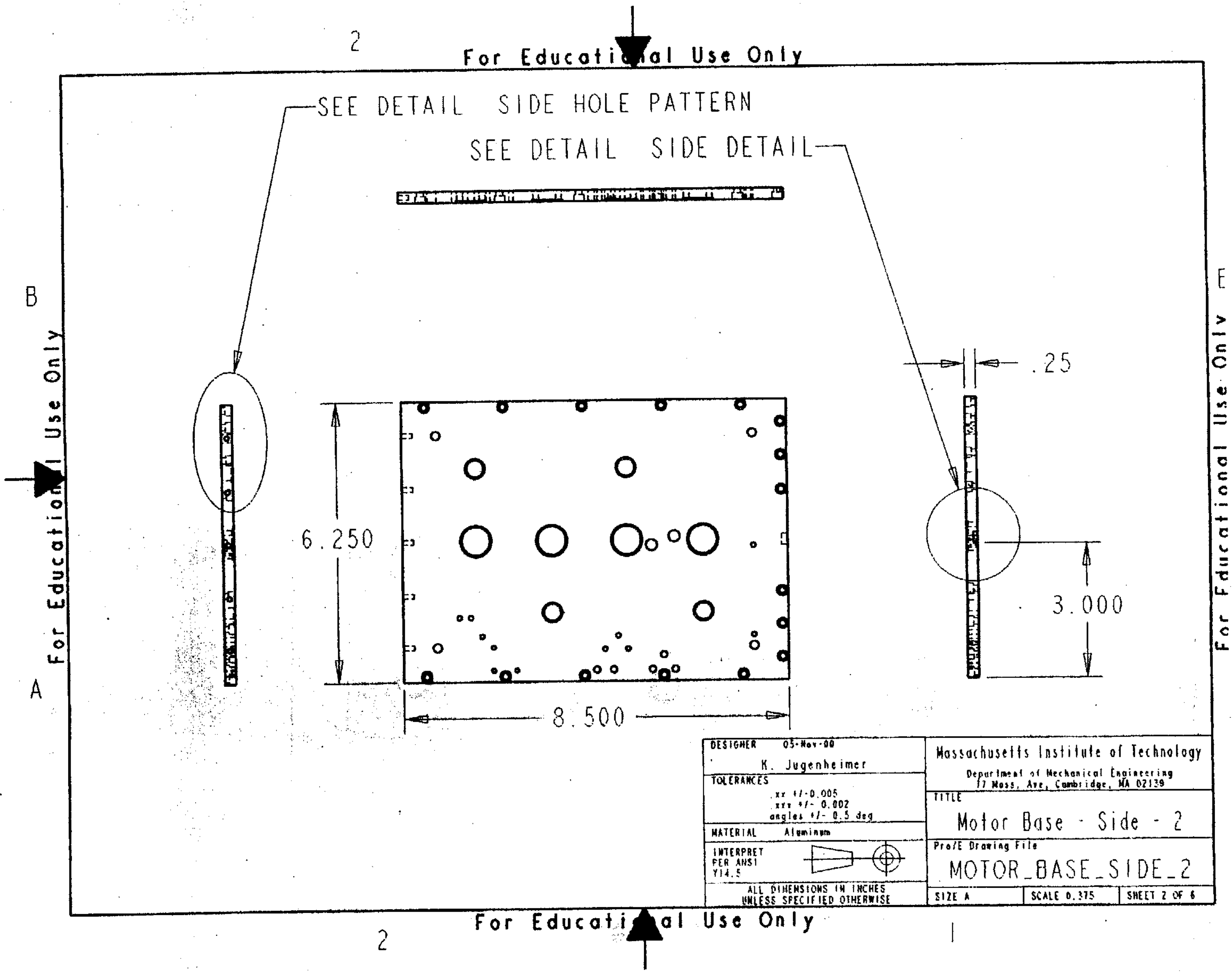

For Educational Use Only
8.500
1.25
4 1/4-20 TAP THRU
.750
.750
.750
6.250
.750
2.50
1.00
1.75
6-32 TAP
B
A
2
1
DESIGNER 31-Oct-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Motor Base - Side
Pro/E Drawing File
MOTOR_BASE_SIDE
SIZE A
SCALE 0.625
SHEET 7 OF 7



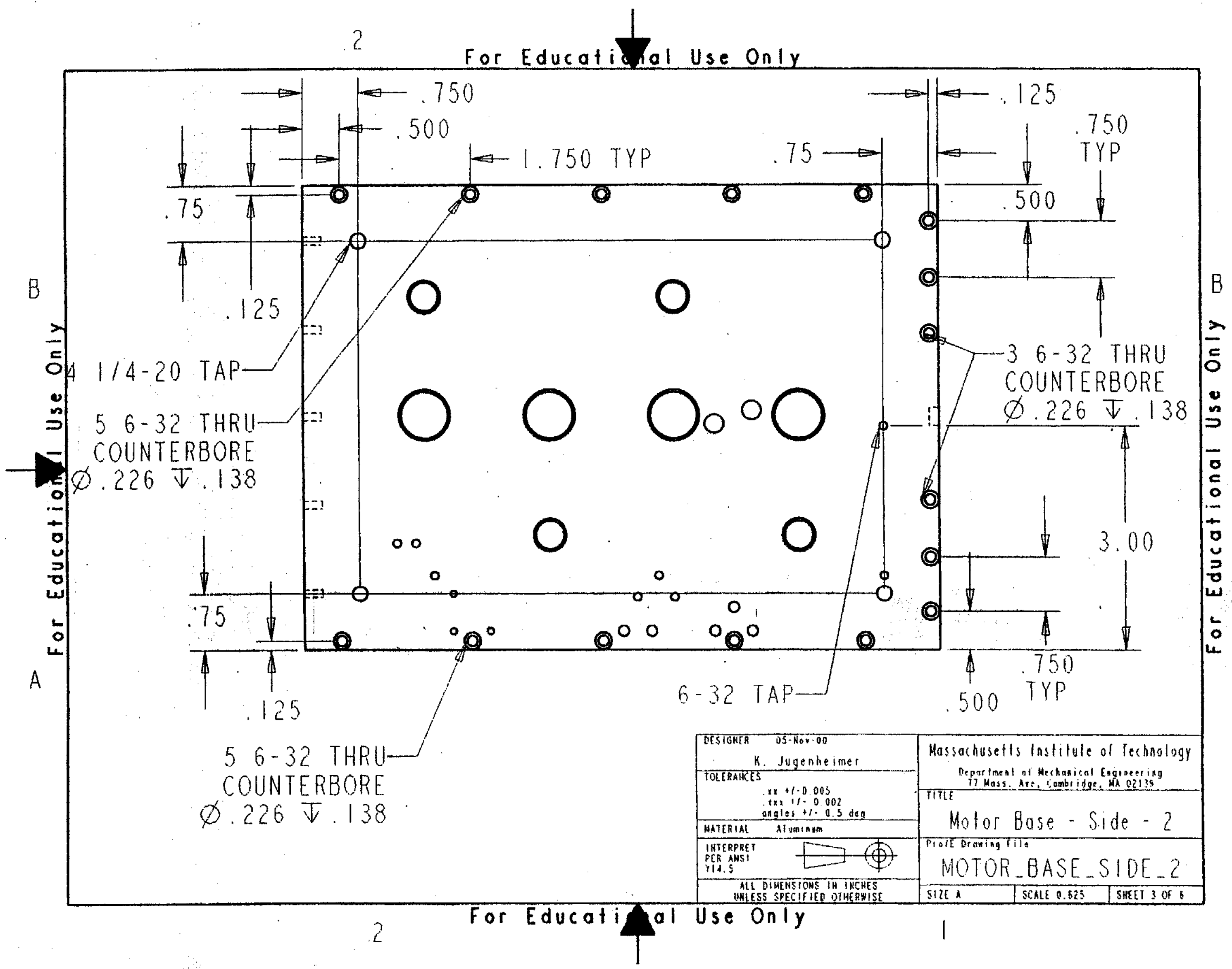
ISOMETRIC VIEW

DESIGNER 05-Nov-90 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Side - 2
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_BASE_SIDE_2
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 0.625 · SHEET 1 OF 6

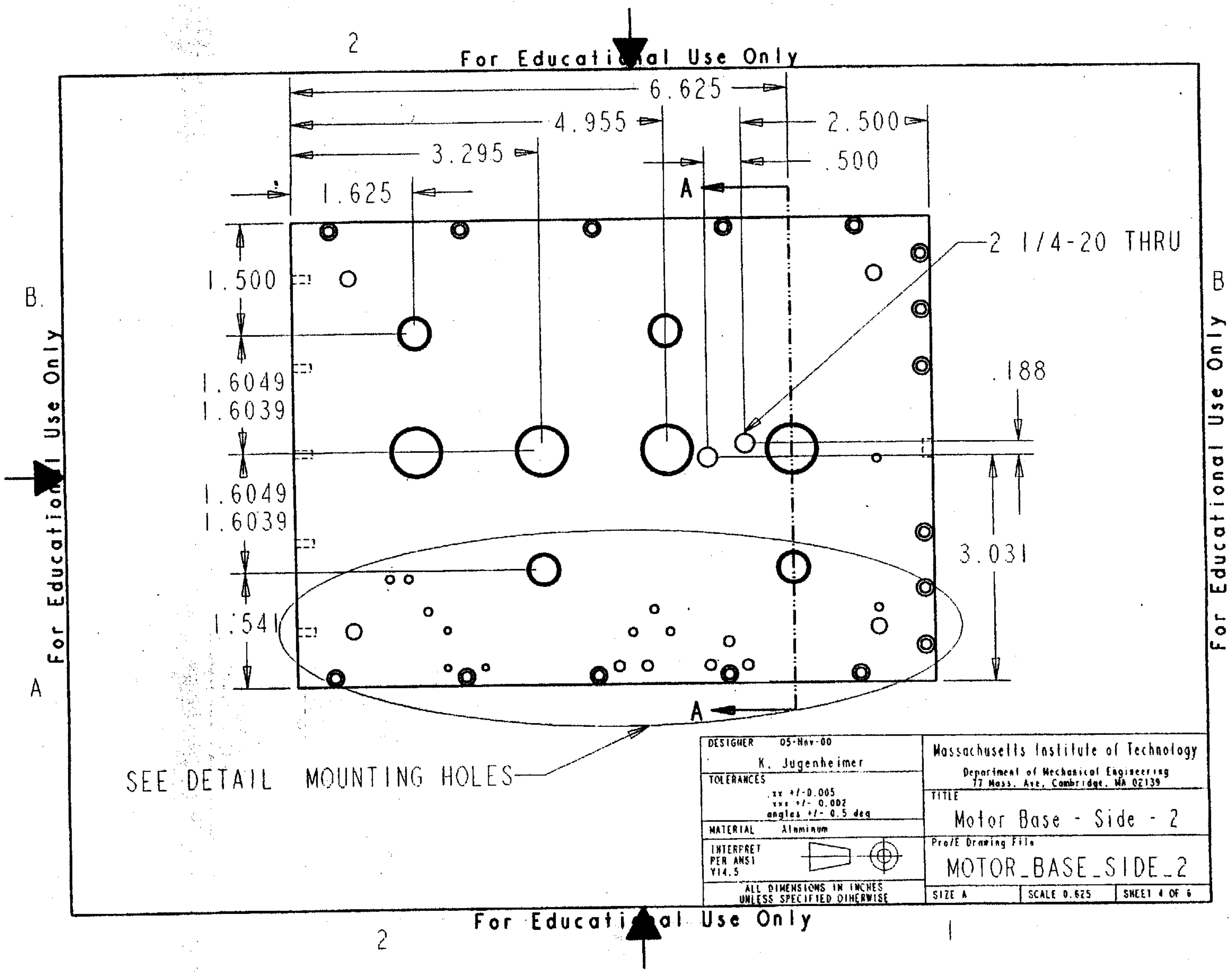
For Educational Use Only

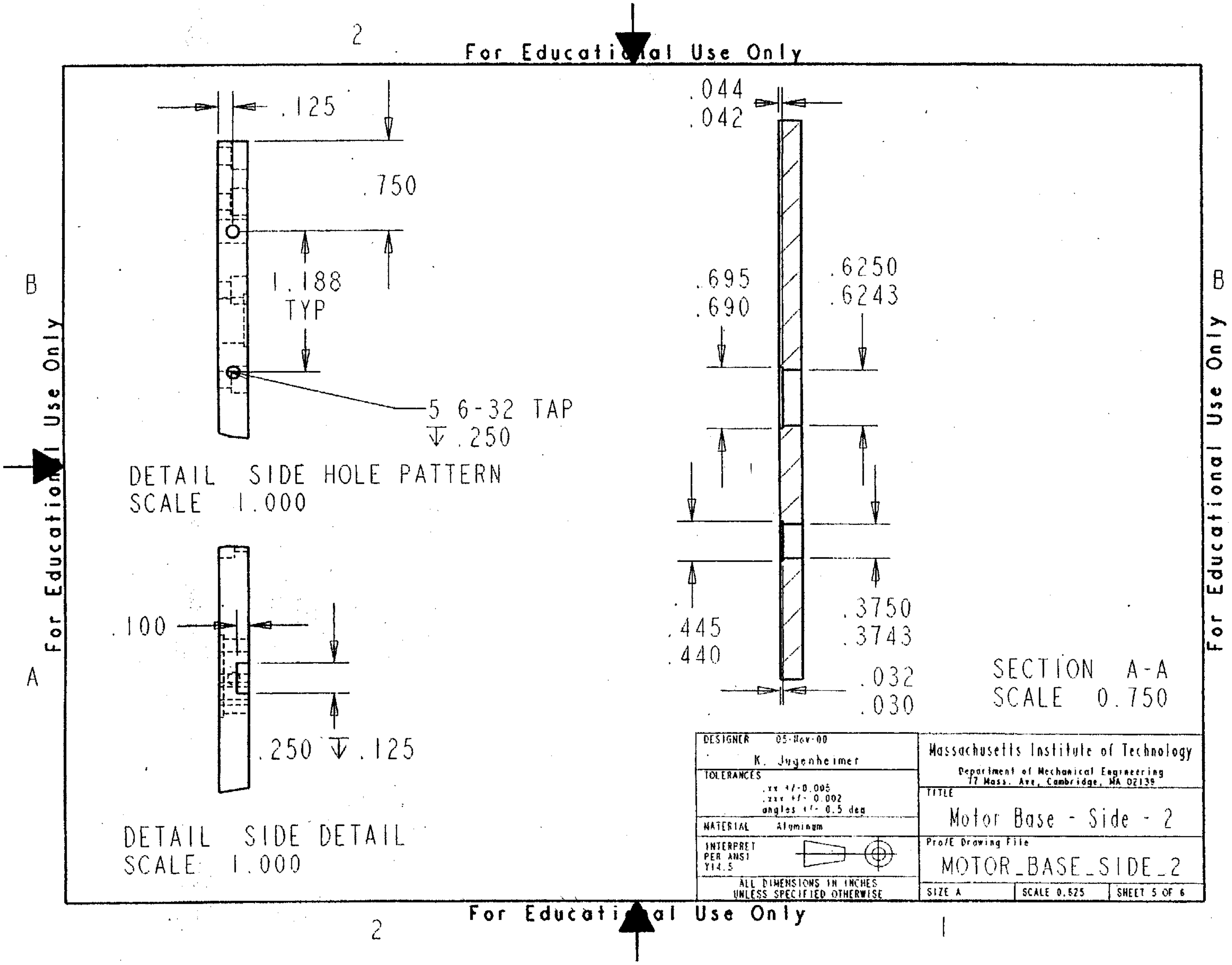


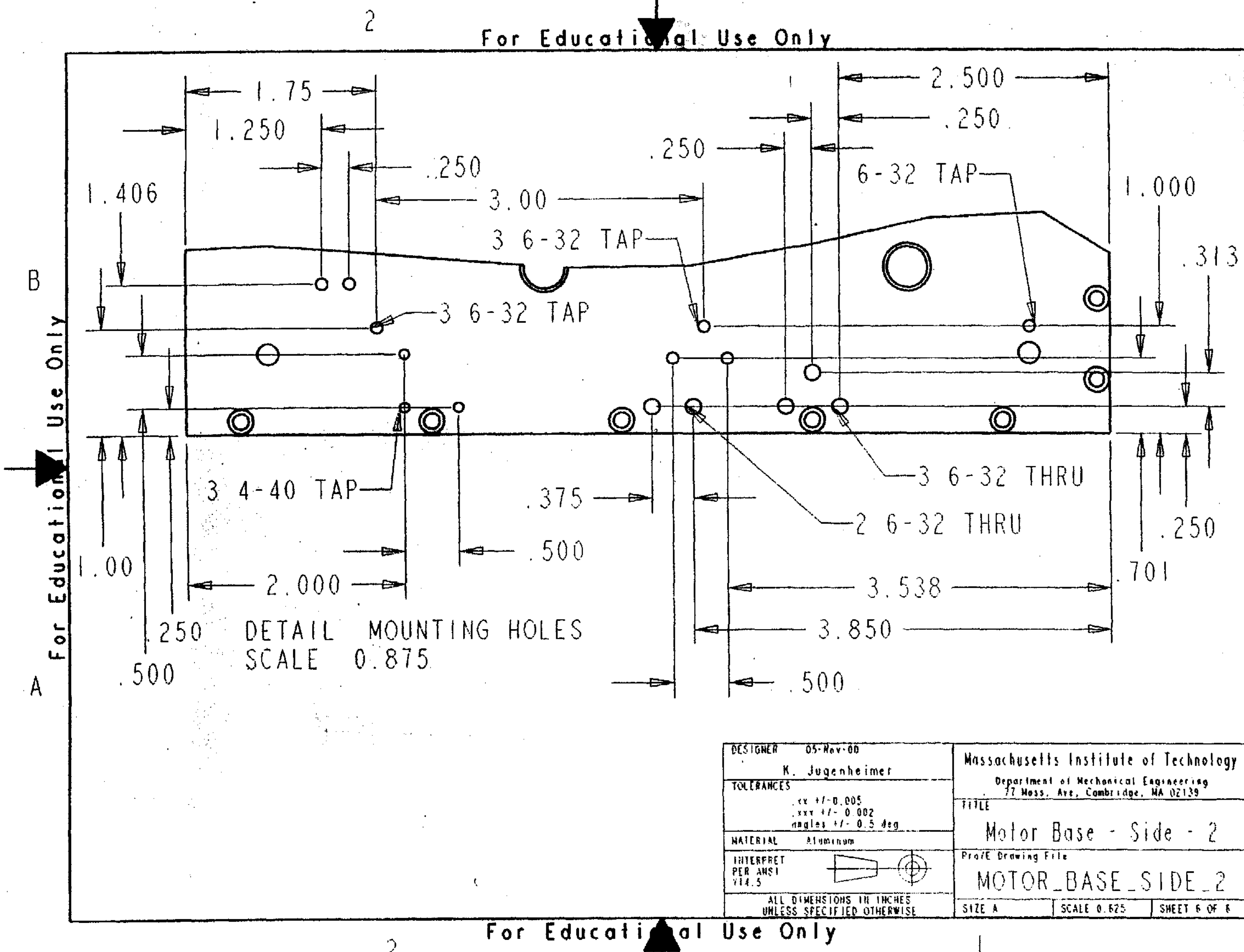
2
For Educational Use Only
SEE DETAIL SIDE HOLE PATTERN
SEE DETAIL SIDE DETAIL
B
A
E
.25
6.250
3.000
8.500
For Educational Use Only
For Educational Use Only
DESIGNER 05-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side - 2
Pro/E Drawing File
MOTOR_BASE_SIDE_2
SIZE A
SCALE 0.375
SHEET 2 OF 6
For Educational Use Only
2


For Educational Use Only
.750
.500
1.750 TYP
.75
.125
.750 TYP
.500
.75
.125
4 1/4-20 TAP
5 6-32 THRU COUNTERBORE ∅.226 ↧.138
3 6-32 THRU COUNTERBORE ∅.226 ↧.138
3.00
.75
.125
6-32 TAP
.750 TYP
.500
5 6-32 THRU COUNTERBORE ∅.226 ↧.138
DESIGNER 05-Nov-00
K. Jugenheimer
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side - 2
Pro/E Drawing File
MOTOR_BASE_SIDE_2
SIZE A
SCALE 0.625
SHEET 3 OF 6

218

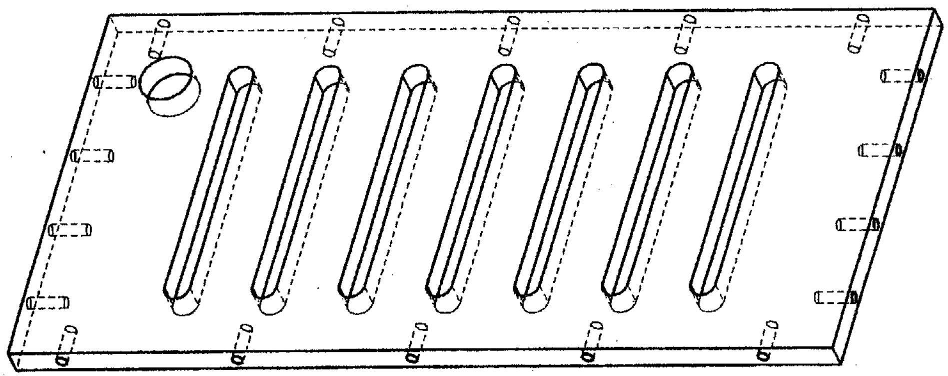

For Educational Use Only
6.625
4.955
2.500
3.295
.500
1.625
A
2 1/4-20 THRU
1.500
1.6049
1.6039
.188
1.6049
1.6039
3.031
1.541
A
SEE DETAIL MOUNTING HOLES
DESIGNER 05-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side - 2
Pro/E Drawing File
MOTOR_BASE_SIDE_2
SIZE A
SCALE 0.625
SHEET 4 OF 6


For Educational Use Only
2
B
A
.125
.750
1.188
TYP
5 6-32 TAP
.250
DETAIL SIDE HOLE PATTERN
SCALE 1.000
.100
.250 .125
DETAIL SIDE DETAIL
SCALE 1.000
.044
.042
.695
.690
.6250
.6243
.445
.440
.3750
.3743
.032
.030
SECTION A-A
SCALE 0.750
DESIGNER 05-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side - 2
Pro/E Drawing File
MOTOR_BASE_SIDE_2
SIZE A
SCALE 0.625
SHEET 5 OF 6
1


1.75
1.250
.250
1.406
3.00
3 6-32 TAP
3 6-32 TAP
.250
2.500
.250
6-32 TAP
1.000
.313
3 4-40 TAP
.375
.500
1.00
2.000
.250
.500
DETAIL MOUNTING HOLES
SCALE 0.875
3 6-32 THRU
2 6-32 THRU
.250
.701
3.538
3.850
.500
DESIGNER 05-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base - Side - 2
Pro/E Drawing File
MOTOR_BASE_SIDE_2
SIZE A
SCALE 0.625
SHEET 6 OF 6

11-7-00

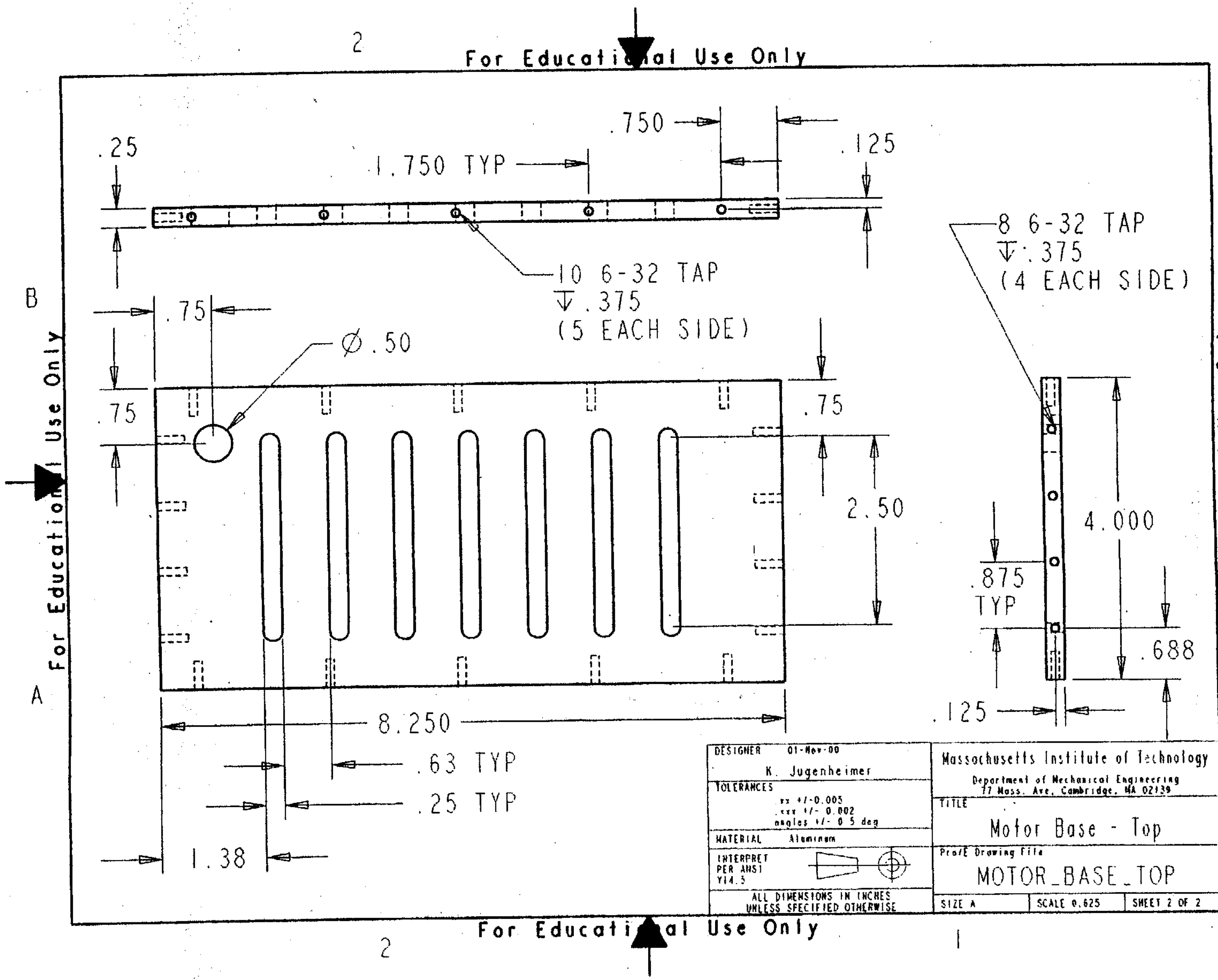
For Educational Use Only



ISOMETRIC VIEW

DESIGNER 01-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base - Top
MATERIAL Aluminum	Pro/E Drawing File MOTOR_BASE_TOP
INTERPRET PER ANSI Y14.5	
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.750 | SHEET 1 OF 2

For Educational Use Only

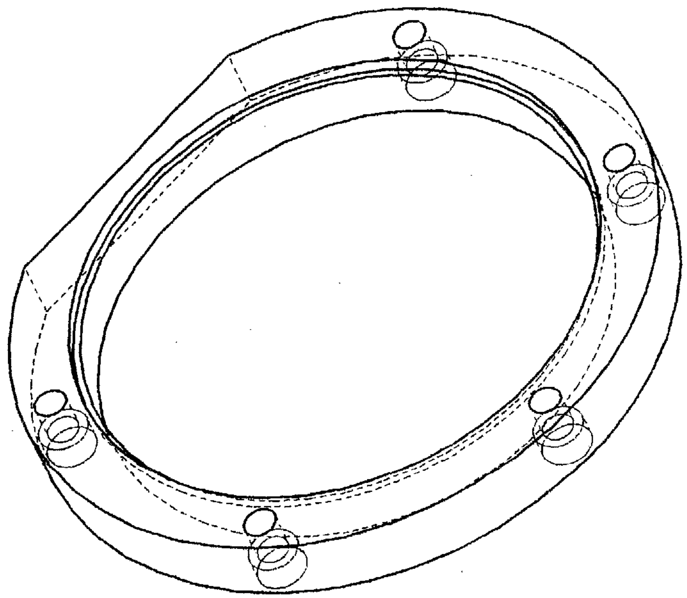

For Educational Use Only
.750
.125
.25
1.750 TYP
10 6-32 TAP
⊽ .375
(5 EACH SIDE)
8 6-32 TAP
⊽ .375
(4 EACH SIDE)
.75
⌀.50
.75
.75
2.50
4.000
.875
TYP
.688
.125
8.250
.63 TYP
.25 TYP
1.38
DESIGNER 01-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Motor Base - Top
Pro/E Drawing File
MOTOR_BASE_TOP
SIZE A
SCALE 0.625
SHEET 2 OF 2

11-10-00

2

B

For Educational Use Only



ISOMETRIC VIEW

A

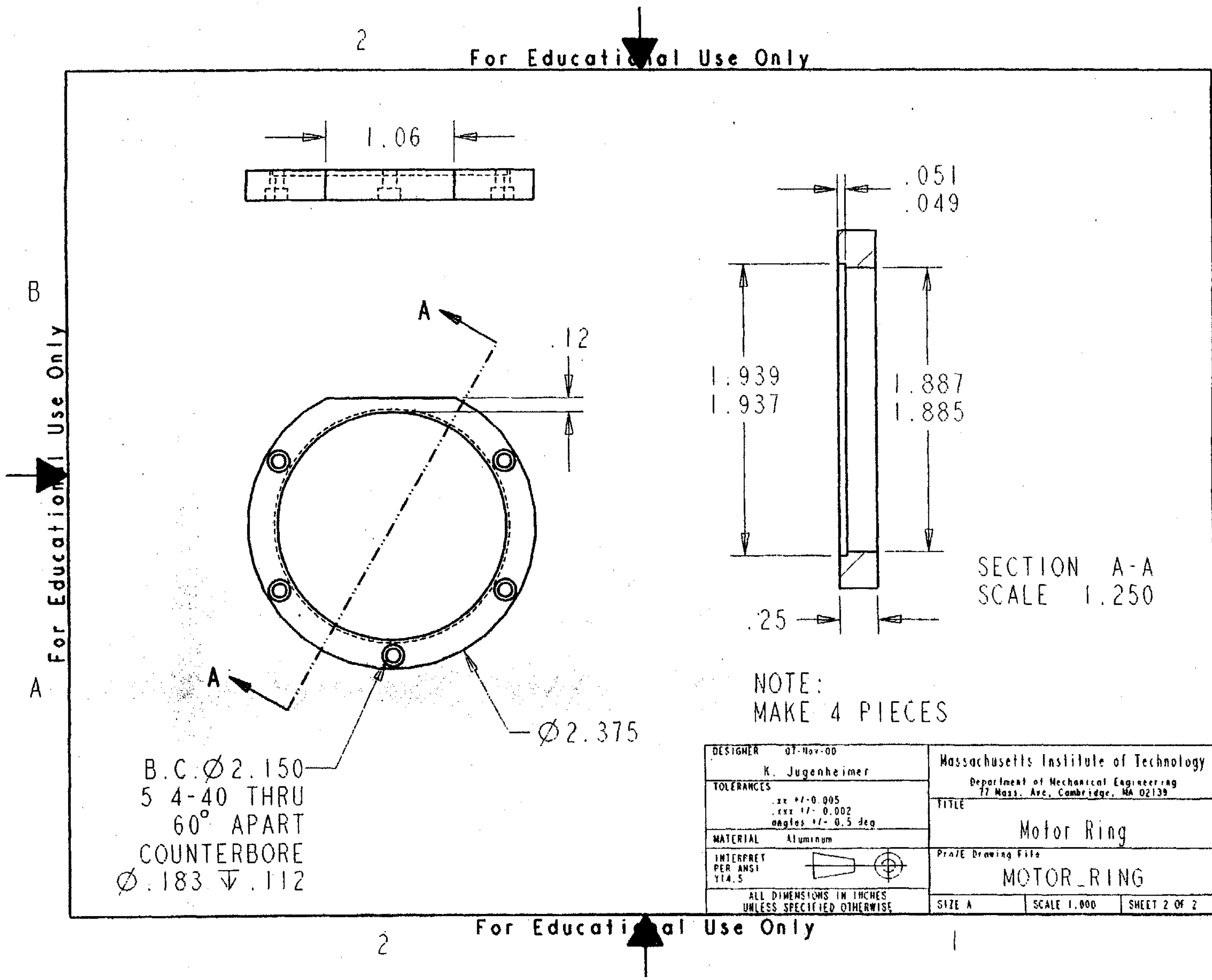
B

For Educational Use Only

DESIGNER 07-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Ring
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_RING
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 2

For Educational Use Only

2 1


For Educational Use Only
1.06
.051
.049
1.939
1.937
1.887
1.885
.12
A
A
B
B
A
2
2
1
SECTION A-A
SCALE 1.250
.25
NOTE:
MAKE 4 PIECES
Ø2.375
B.C.Ø2.150
5 4-40 THRU
60° APART
COUNTERBORE
Ø.183 ⫐ .112
DESIGNER 07-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Ring
Pro/E Drawing File
MOTOR_RING
SIZE A
SCALE 1.000
SHEET 2 OF 2

2

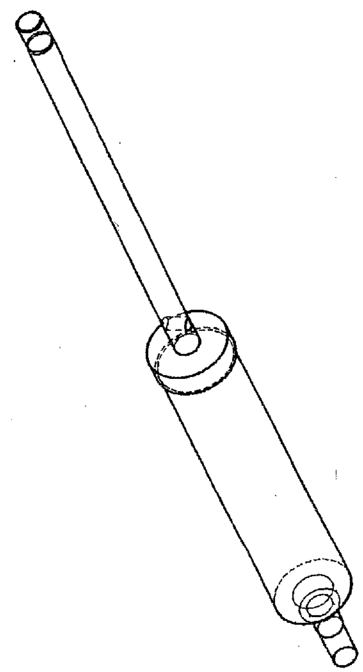
B

A

For Educational Use Only

E

For Educational Use Only

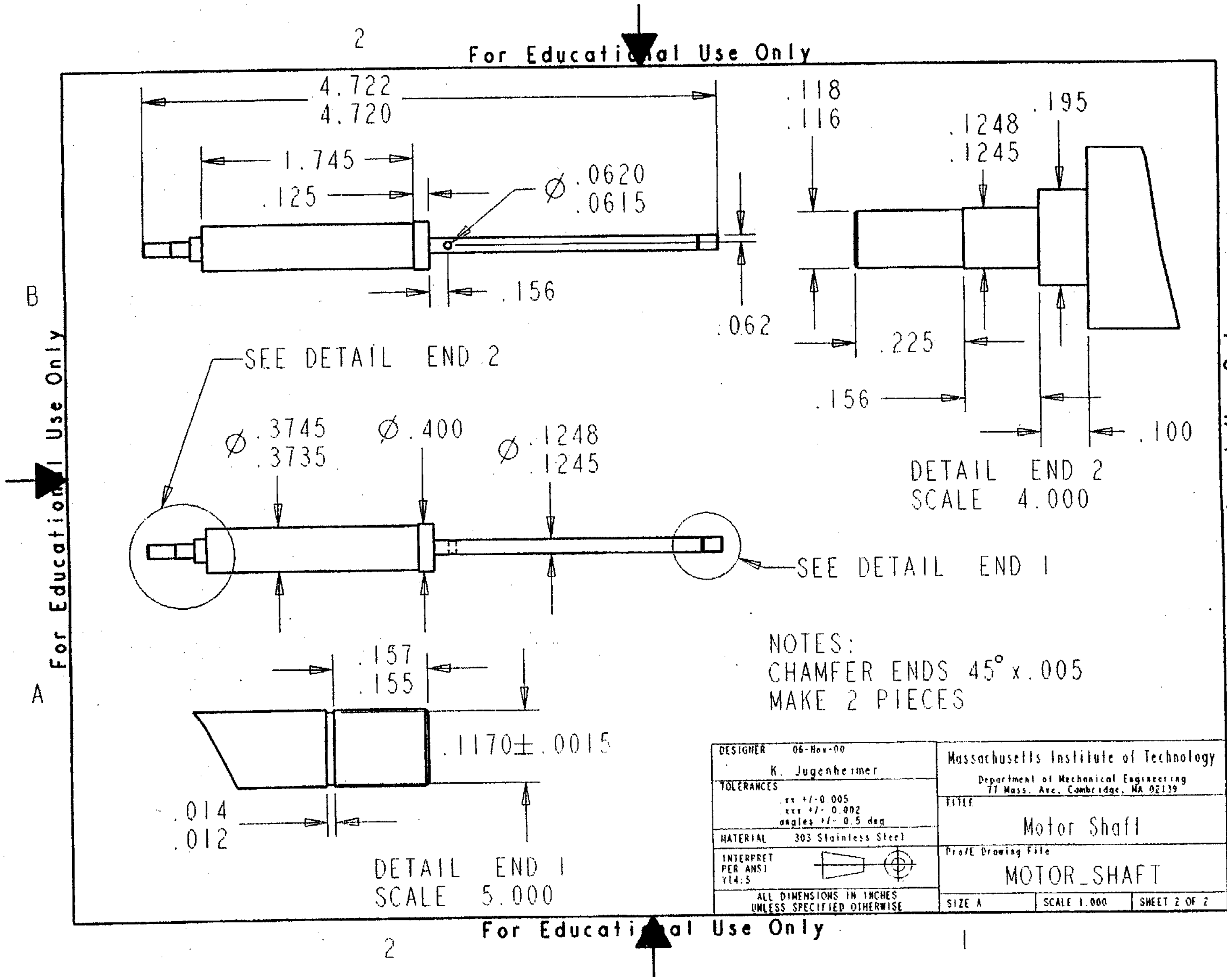


DESIGNER 07-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave., Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Shaft
MATERIAL Steel	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_SHAFT
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 1.500 · SHEET 1 OF 2

For Educational Use Only

2

1

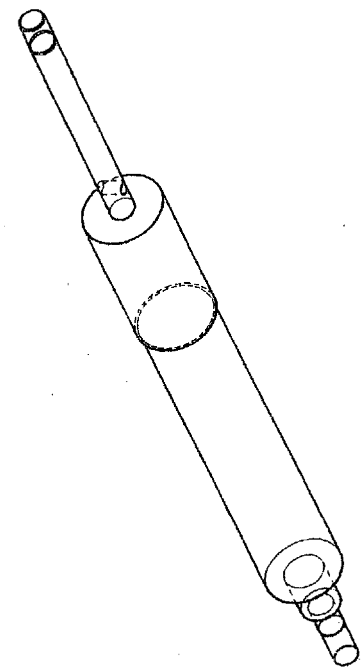


For Educational Use Only
4.722
4.720
1.745
.125
∅ .0620
.0615
.156
.062
.118
.116
.1248
.1245
.195
.225
.156
.100
DETAIL END 2
SCALE 4.000
SEE DETAIL END 2
∅ .3745
.3735
∅ .400
∅ .1248
.1245
SEE DETAIL END 1
.157
.155
.1170±.0015
.014
.012
DETAIL END 1
SCALE 5.000
NOTES:
CHAMFER ENDS 45° x .005
MAKE 2 PIECES
DESIGNER 06-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL 303 Stainless Steel
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Motor Shaft
Pro/E Drawing File
MOTOR_SHAFT
SIZE A
SCALE 1.000
SHEET 2 OF 2

2

B

A



DESIGNER 07-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Shaft - Long
MATERIAL Steel	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_SHAFT_LONG
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.500 | SHEET 1 OF 2

For Educational Use Only

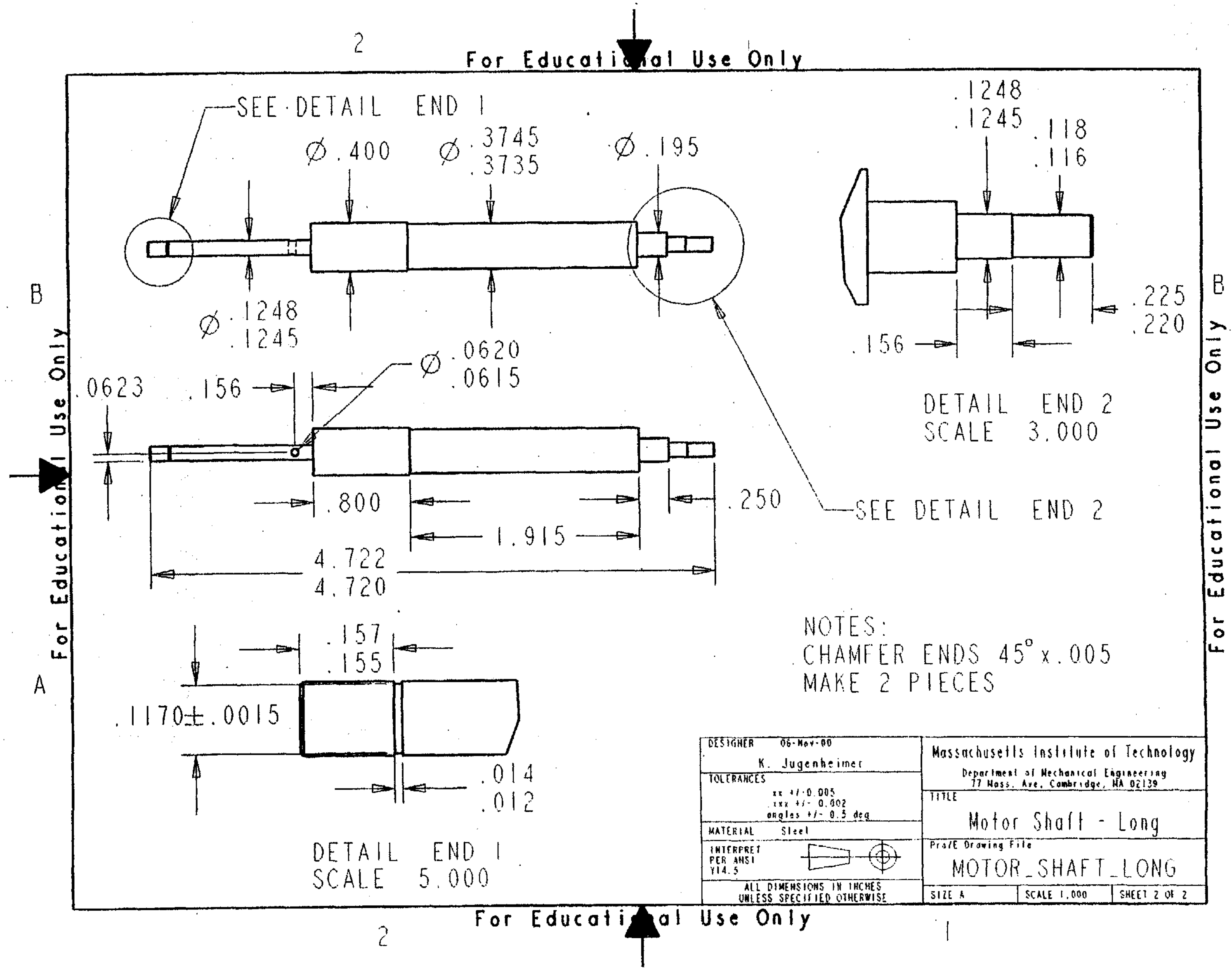
2

1

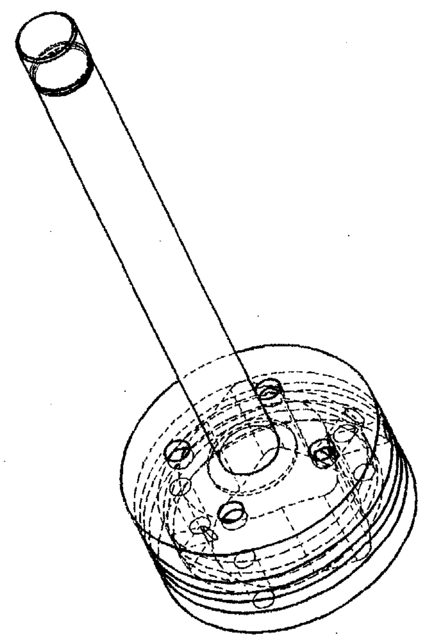
B

For Educational Use Only

For Educational Use Only

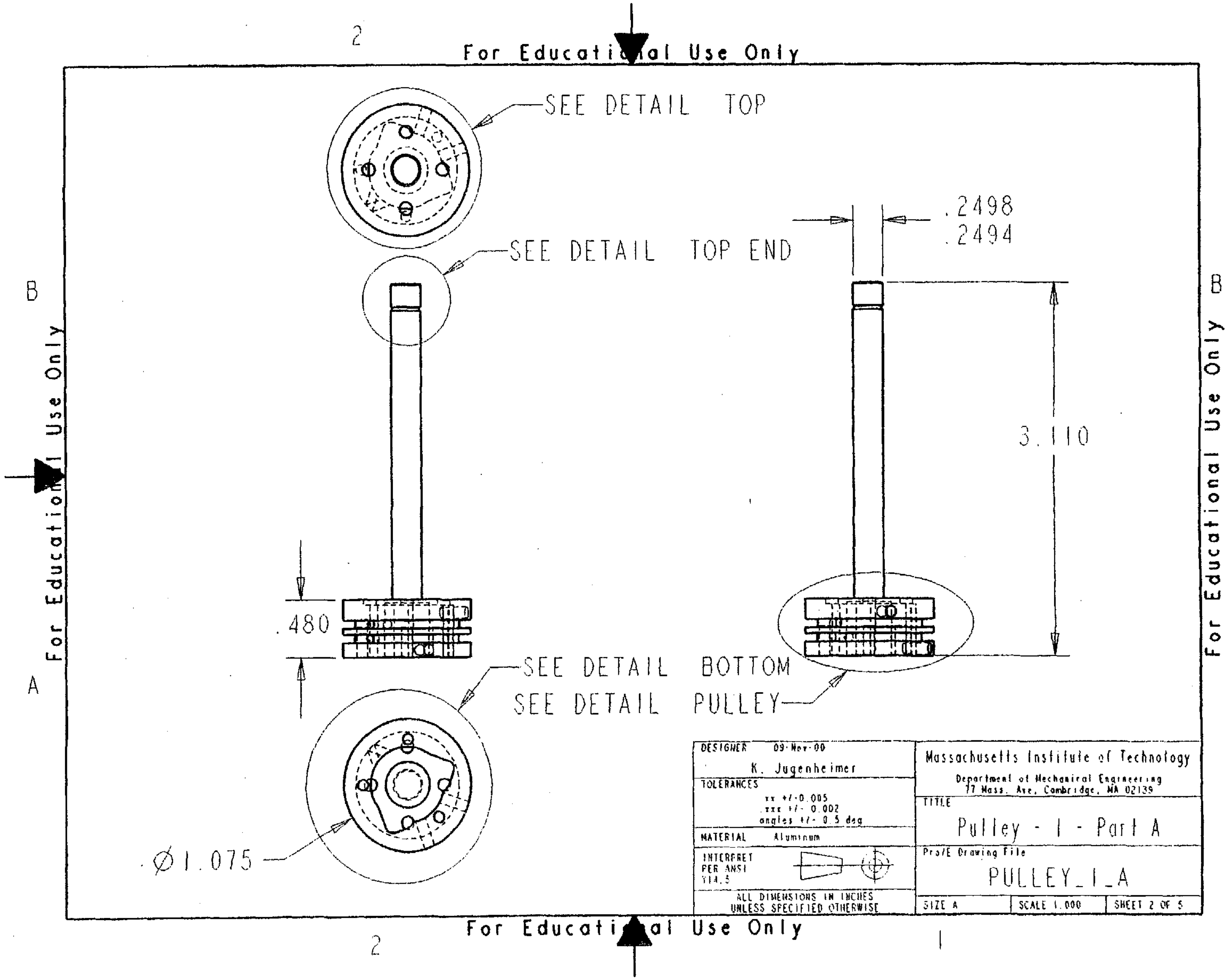

For Educational Use Only
SEE DETAIL END 1
Ø .400
Ø .3745 .3735
Ø .195
Ø .1248 .1245
Ø .0620 .0615
.0623
.156
.800
1.915
.250
4.722 4.720
SEE DETAIL END 2
.1248 .1245
.118 .116
.225 .220
.156
DETAIL END 2
SCALE 3.000
.157 .155
.1170±.0015
.014 .012
DETAIL END 1
SCALE 5.000
NOTES:
CHAMFER ENDS 45° x .005
MAKE 2 PIECES
DESIGNER 06-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Steel
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Shaft - Long
Pro/E Drawing File
MOTOR_SHAFT_LONG
SIZE A
SCALE 1.000
SHEET 2 OF 2

11-10-00

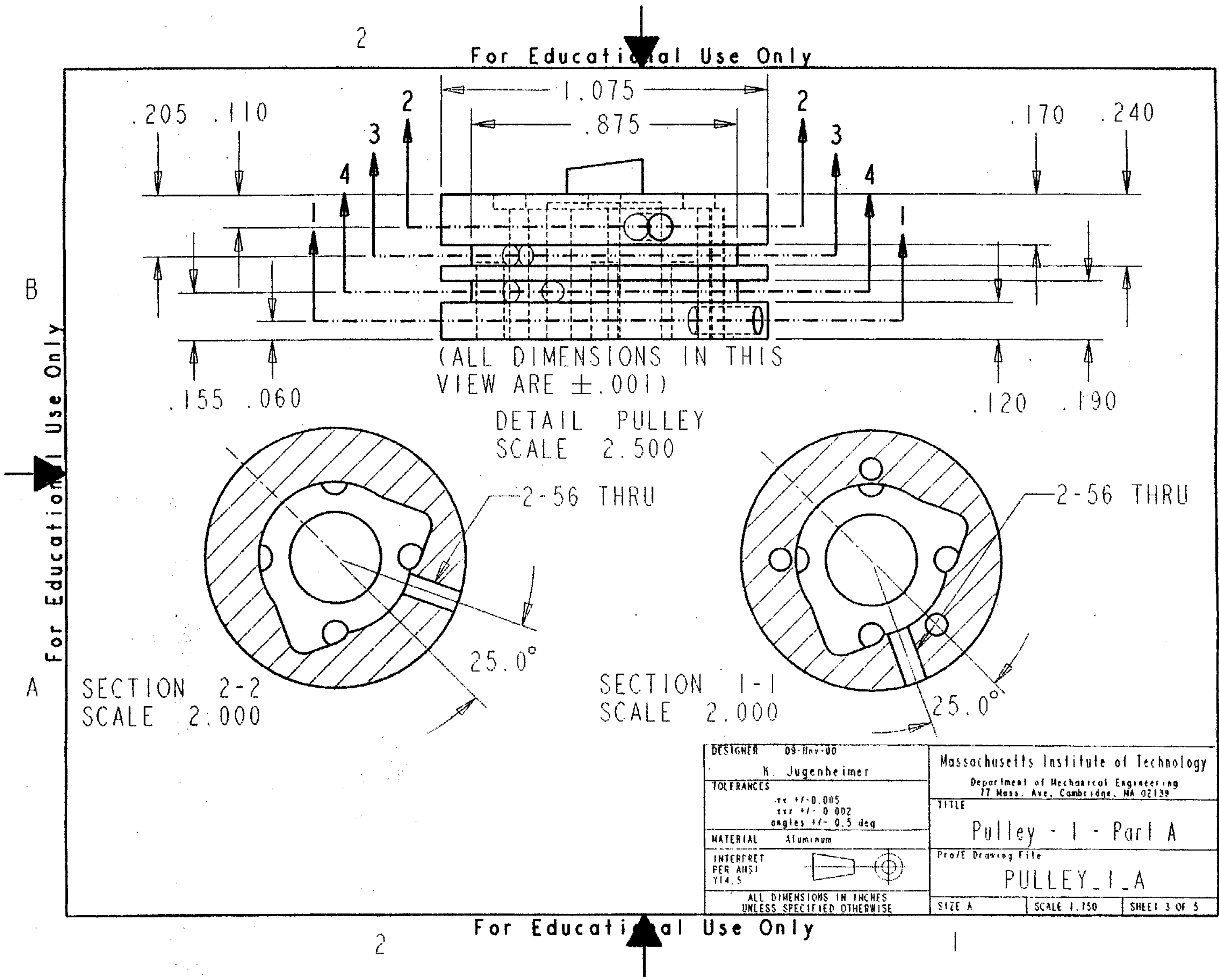


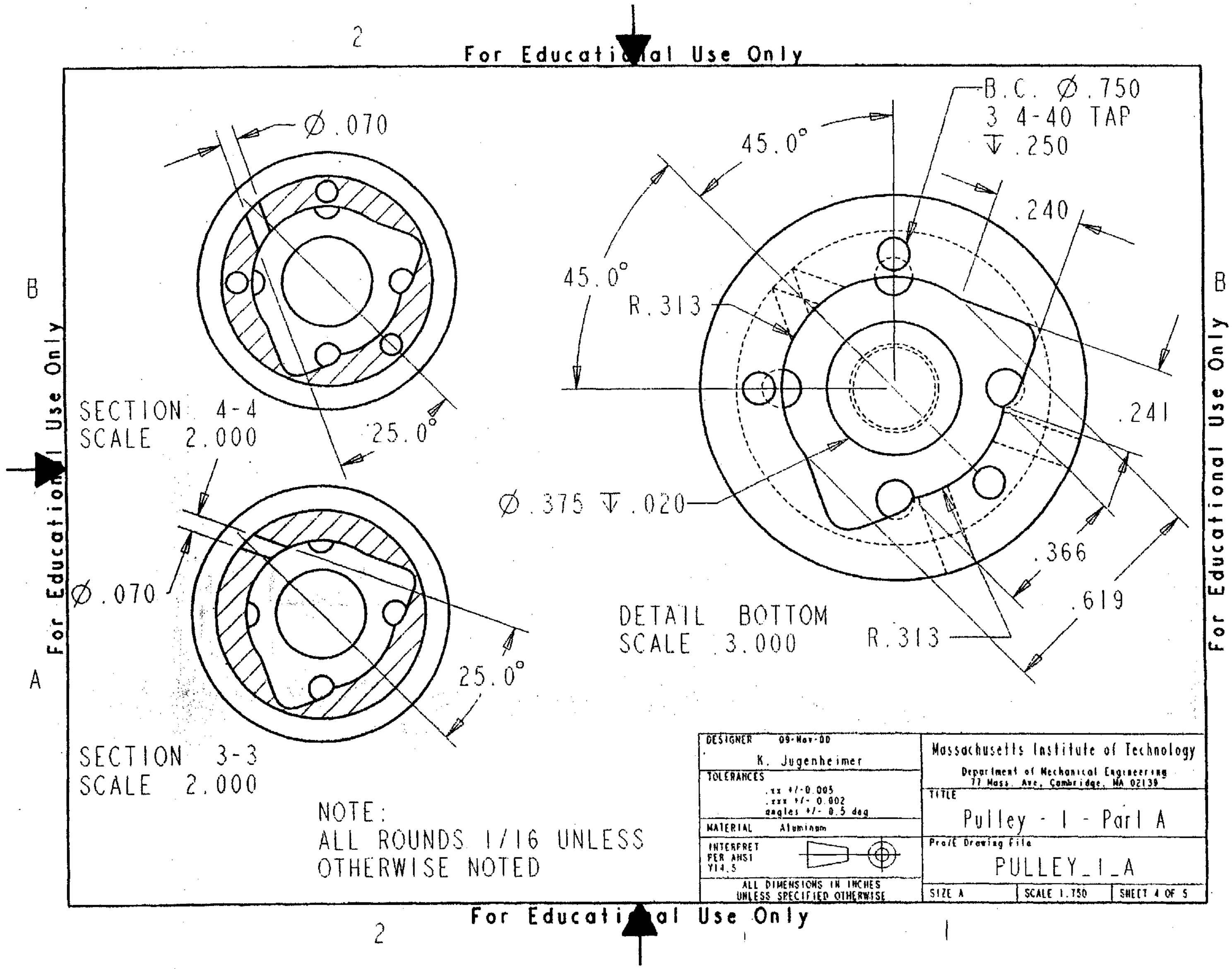
ISOMETRIC VIEW

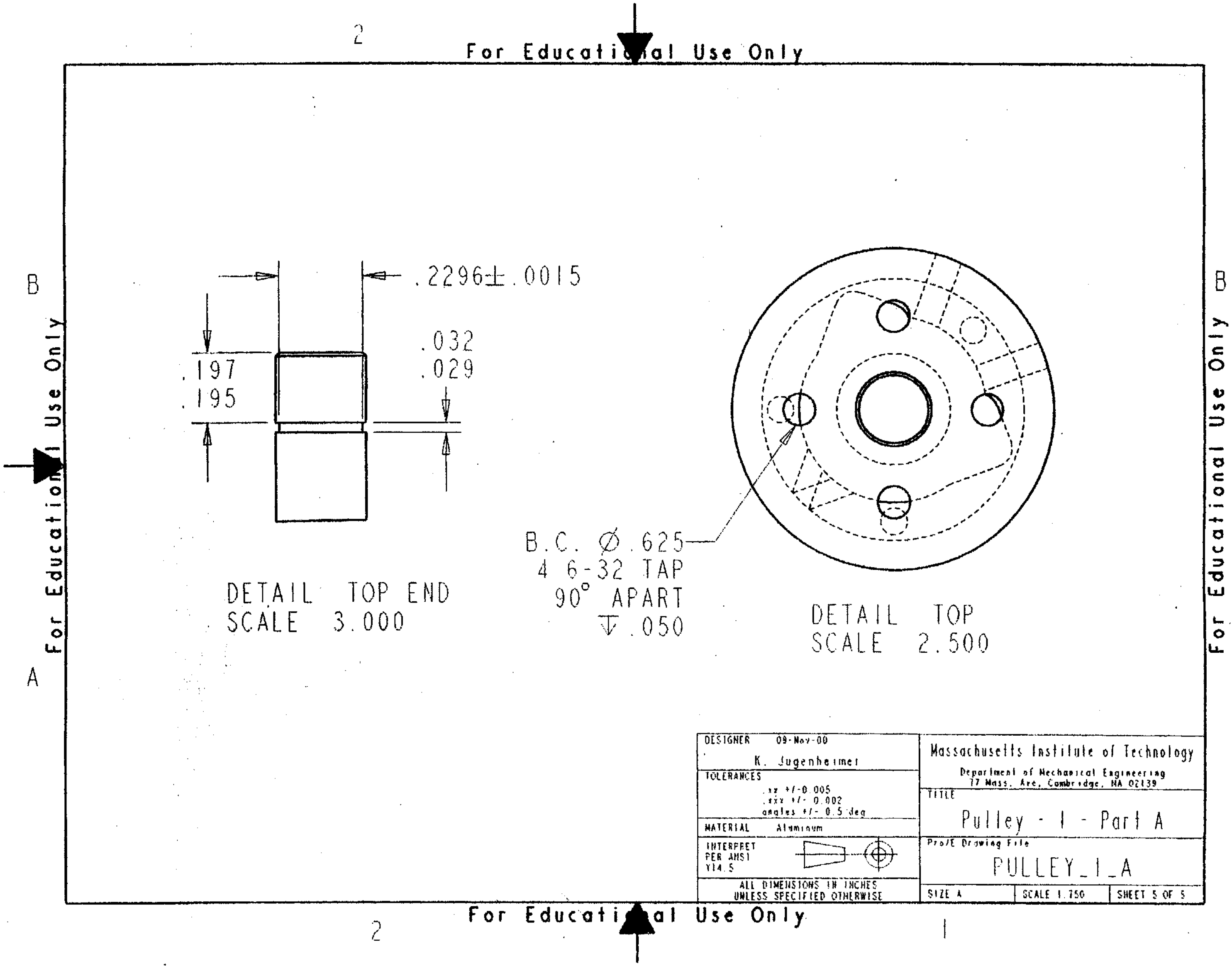
DESIGNER 09-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 1 - Part A
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_1_A
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.750 | SHEET 1 OF 5



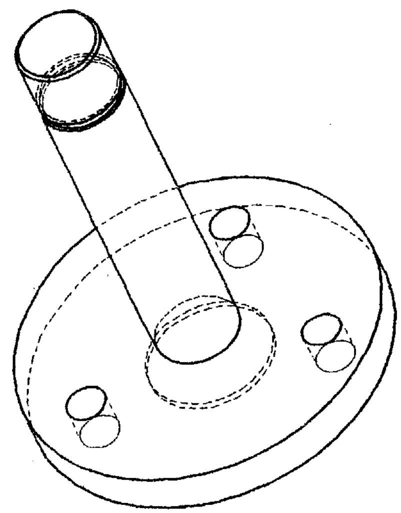
For Educational Use Only
2
SEE DETAIL TOP
SEE DETAIL TOP END
.2498
.2494
B
3.110
.480
A
SEE DETAIL BOTTOM
SEE DETAIL PULLEY
Ø1.075
DESIGNER 09-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 1 - Part A
Pro/E Drawing File
PULLEY_1_A
SIZE A
SCALE 1.000
SHEET 2 OF 5
1


For Educational Use Only
1.075
.875
.205 .110
.170 .240
2
3
4
1
.155 .060
.120 .190
(ALL DIMENSIONS IN THIS VIEW ARE ±.001)
DETAIL PULLEY
SCALE 2.500
2-56 THRU
25.0°
SECTION 2-2
SCALE 2.000
SECTION 1-1
SCALE 2.000
B
A
DESIGNER 09-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 1 - Part A
Pro/E Drawing File
PULLEY_1_A
SIZE A
SCALE 1.750
SHEET 3 OF 5


For Educational Use Only
B.C. Ø.750
3 4-40 TAP
↧.250
45.0°
Ø.070
.240
45.0°
R.313
.241
SECTION 4-4
SCALE 2.000
25.0°
Ø.375 ↧.020
.366
Ø.070
.619
DETAIL BOTTOM
SCALE 3.000
R.313
25.0°
SECTION 3-3
SCALE 2.000
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 09-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 1 - Part A
ProE Drawing File
PULLEY_1_A
SIZE A
SCALE 1.750
SHEET 4 OF 5


For Educational Use Only
.2296±.0015
.197
.195
.032
.029
DETAIL TOP END
SCALE 3.000
B.C. Ø.625
4 6-32 TAP
90° APART
↧.050
DETAIL TOP
SCALE 2.500
DESIGNER 09-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - I - Part A
Pro/E Drawing File
PULLEY_I_A
SIZE A
SCALE 1.750
SHEET 5 OF 5

11-10 02



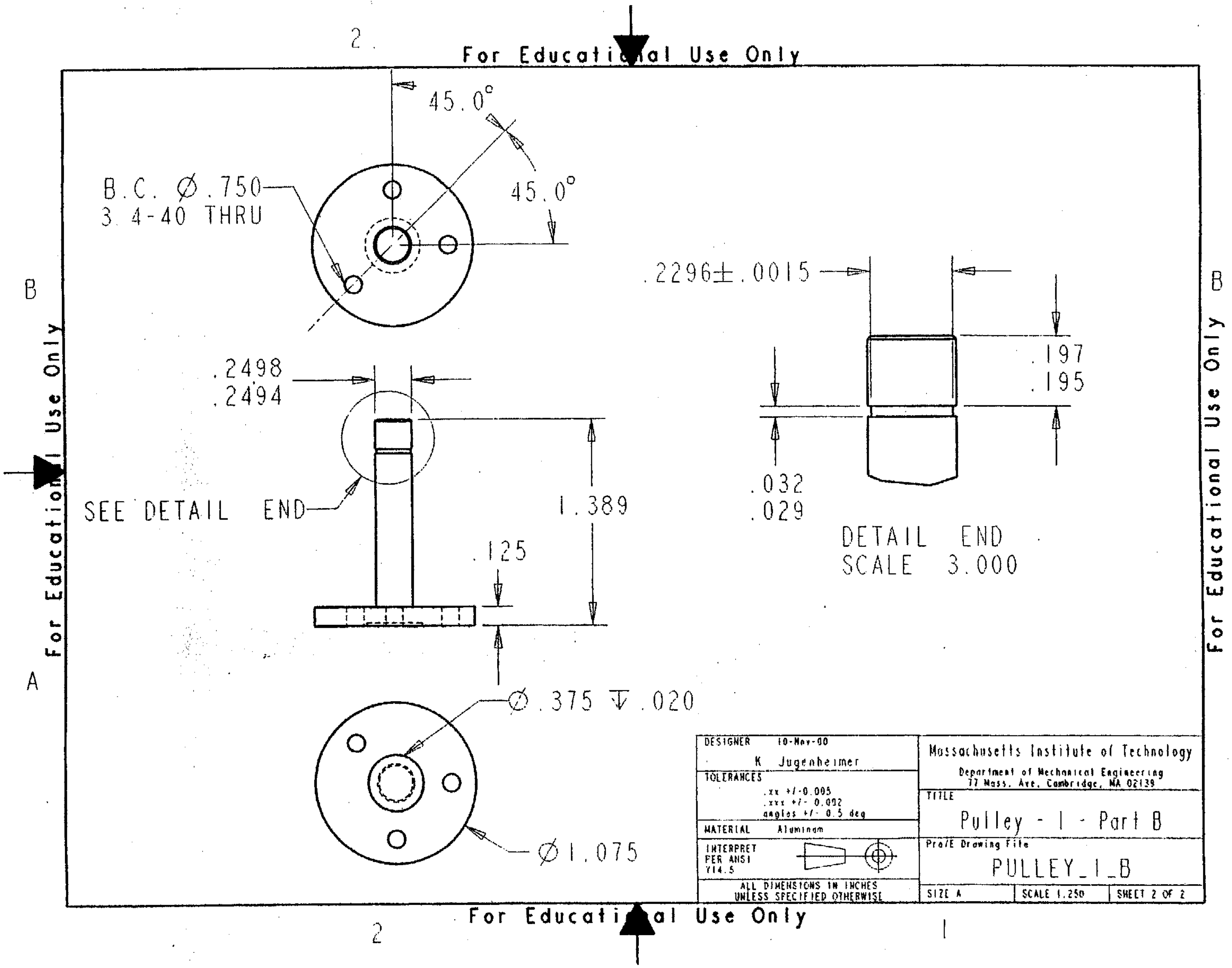
ISOMETRIC VIEW

DESIGNER 10-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 1 - Part B
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_1_B
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 2.500 / SHEET 1 OF 2

For Educational Use Only

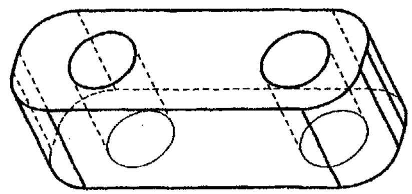
For Educational Use Only

For Educational Use Only


For Educational Use Only
45.0°
45.0°
B.C. Ø .750
3 4-40 THRU
.2296±.0015
.197
.195
.2498
.2494
.032
.029
SEE DETAIL END
1.389
DETAIL END
SCALE 3.000
.125
Ø .375 ↧ .020
Ø 1.075
DESIGNER 10-Nov-00
K Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 1 - Part B
Pro/E Drawing File
PULLEY_1_B
SIZE A
SCALE 1.250
SHEET 2 OF 2

2

B



ISOMETRIC VIEW

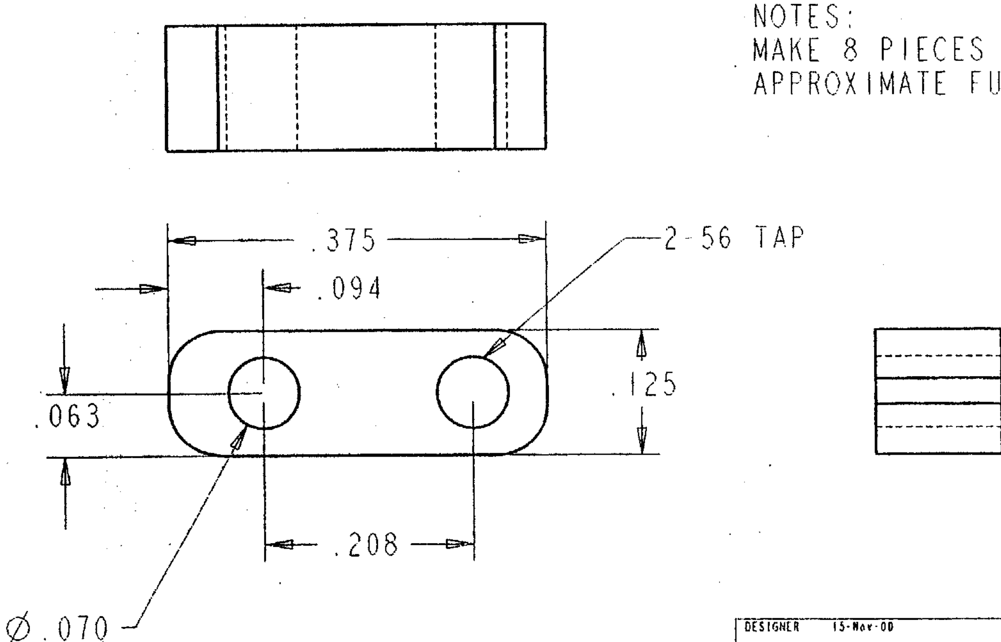
A

DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - I- Part C
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_I_C
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 7.000 | SHEET 1 OF 2

For Educational Use Only

2 1

For Educational Use Only



NOTES:
MAKE 8 PIECES
APPROXIMATE FULL ROUND ON ENDS

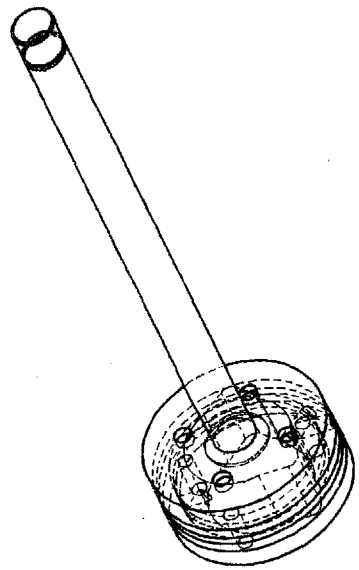
DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 1 - Part C
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_1_C
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 7.000 · SHEET 2 OF 2

For Educational Use Only

11-10-00

2

B



ISOMETRIC VIEW

A

DESIGNER 10-May-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 2 - Part A
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_2_A
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.250 | SHEET 1 OF 5

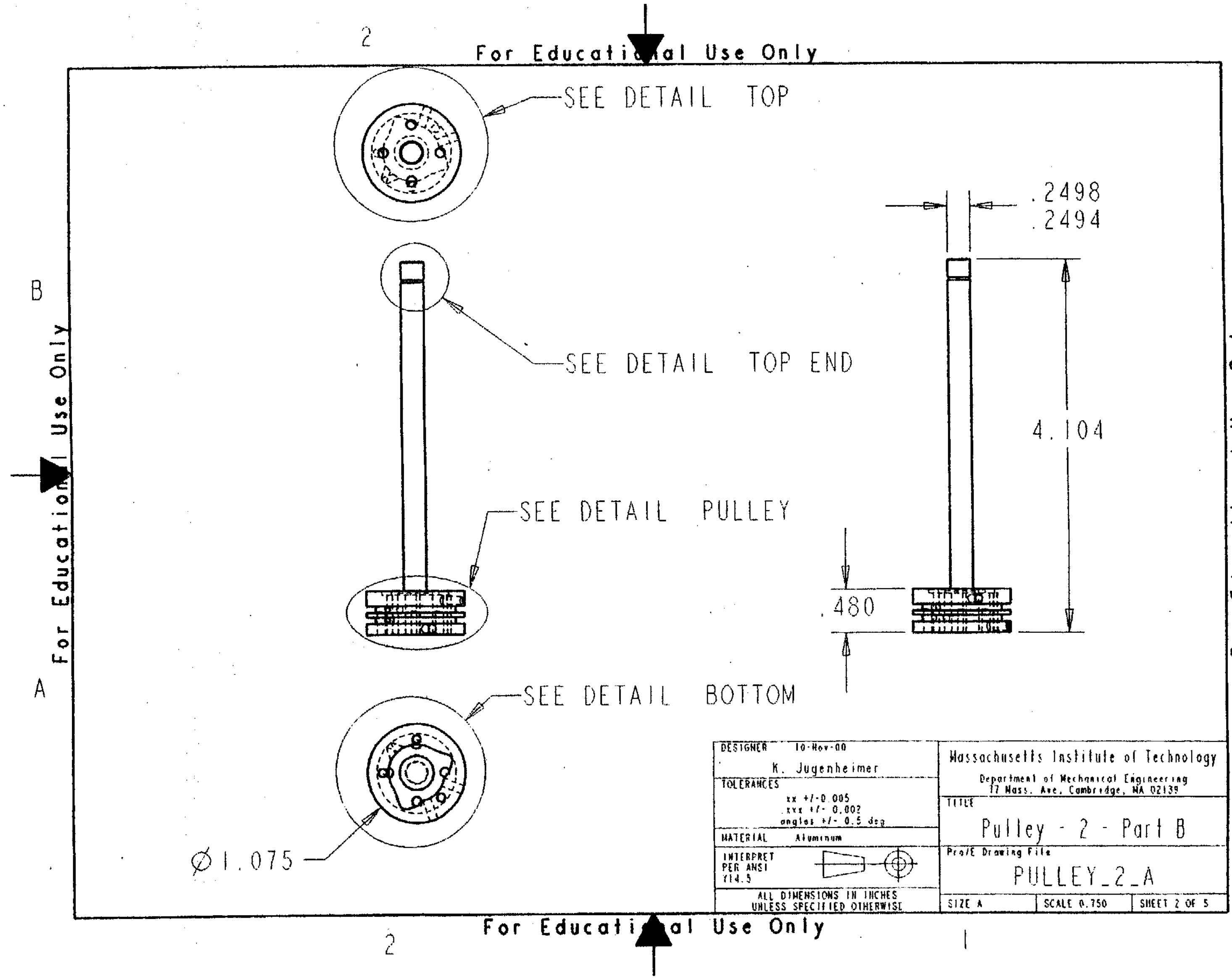
B

For Educational Use Only

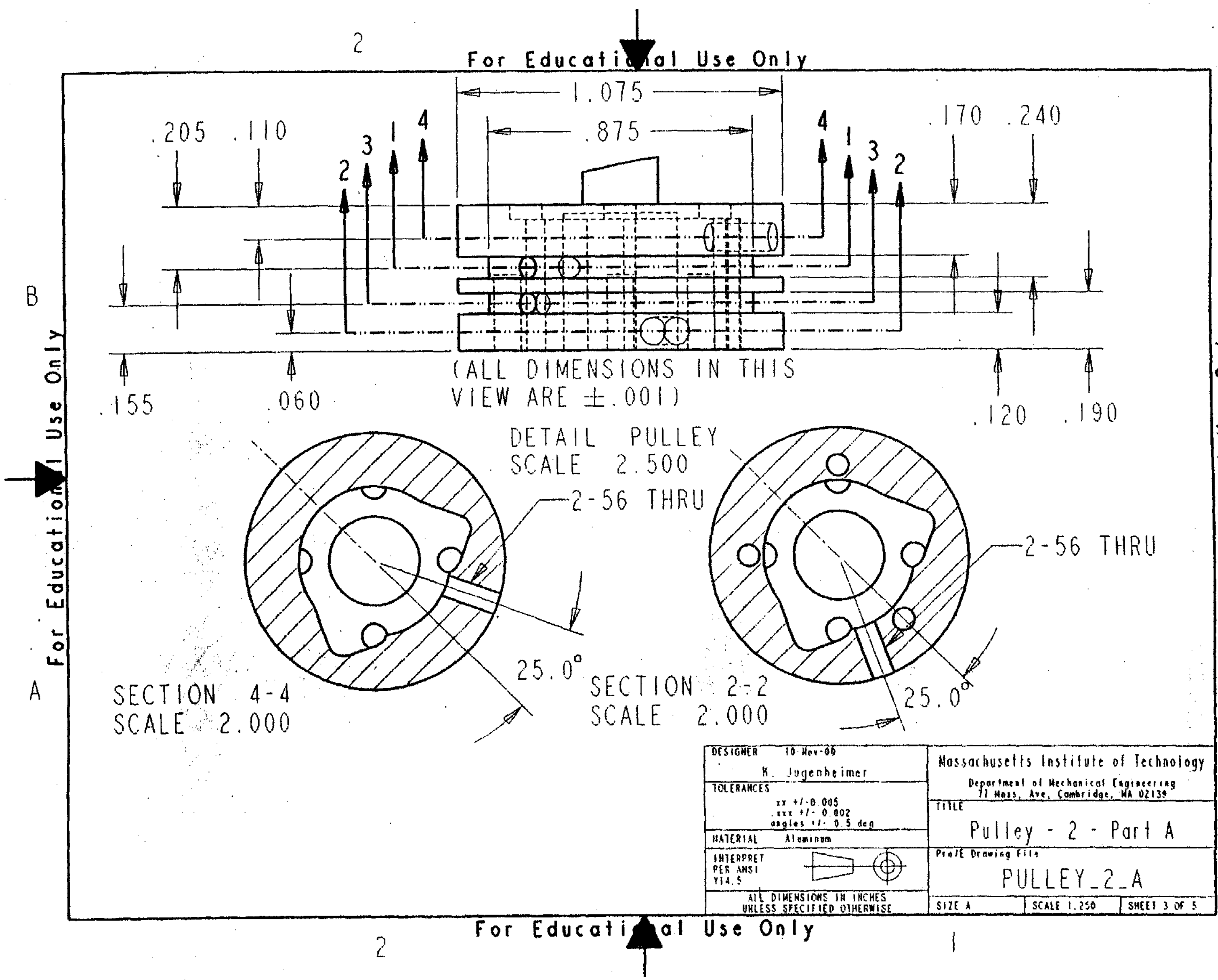
For Educational Use Only

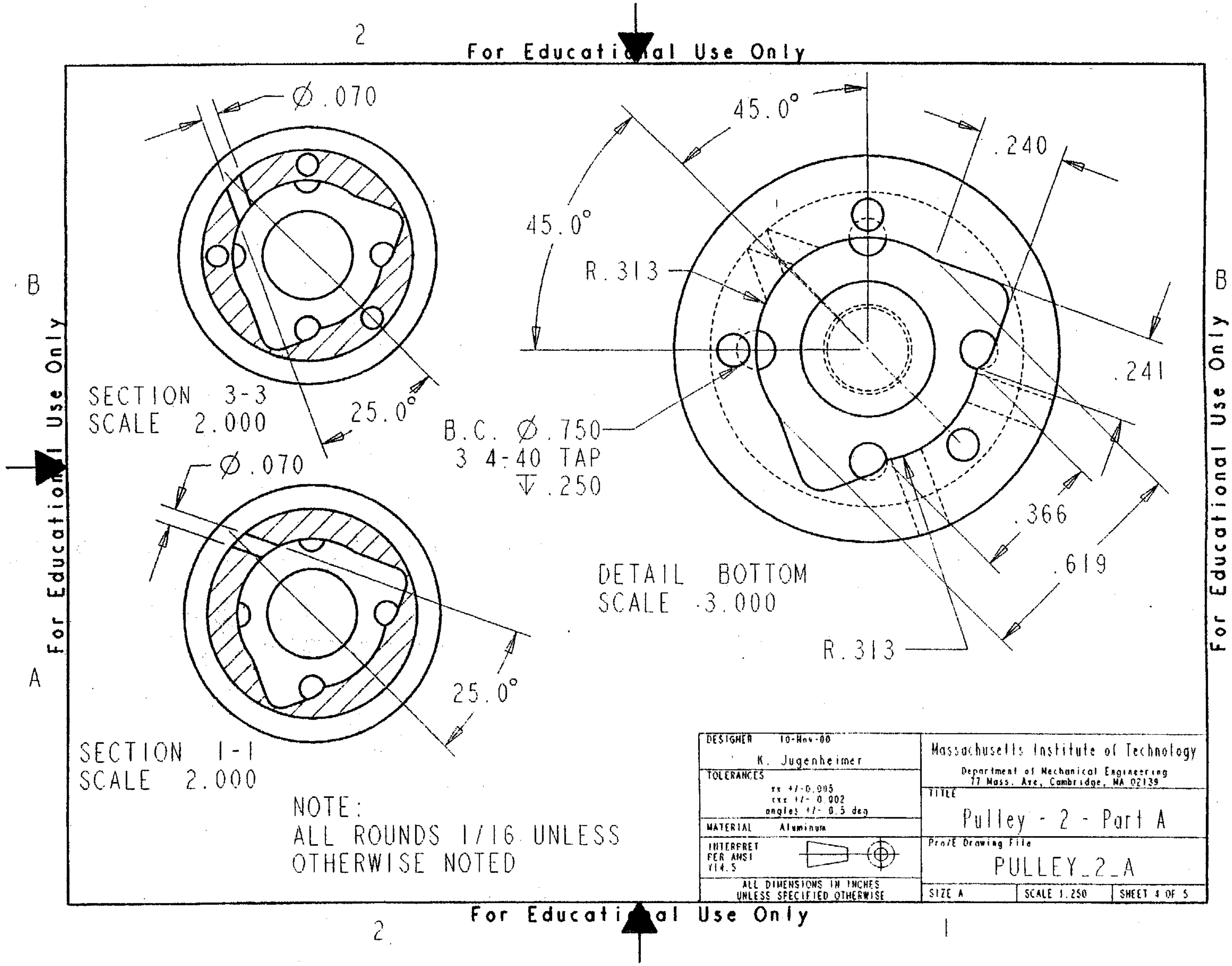
2

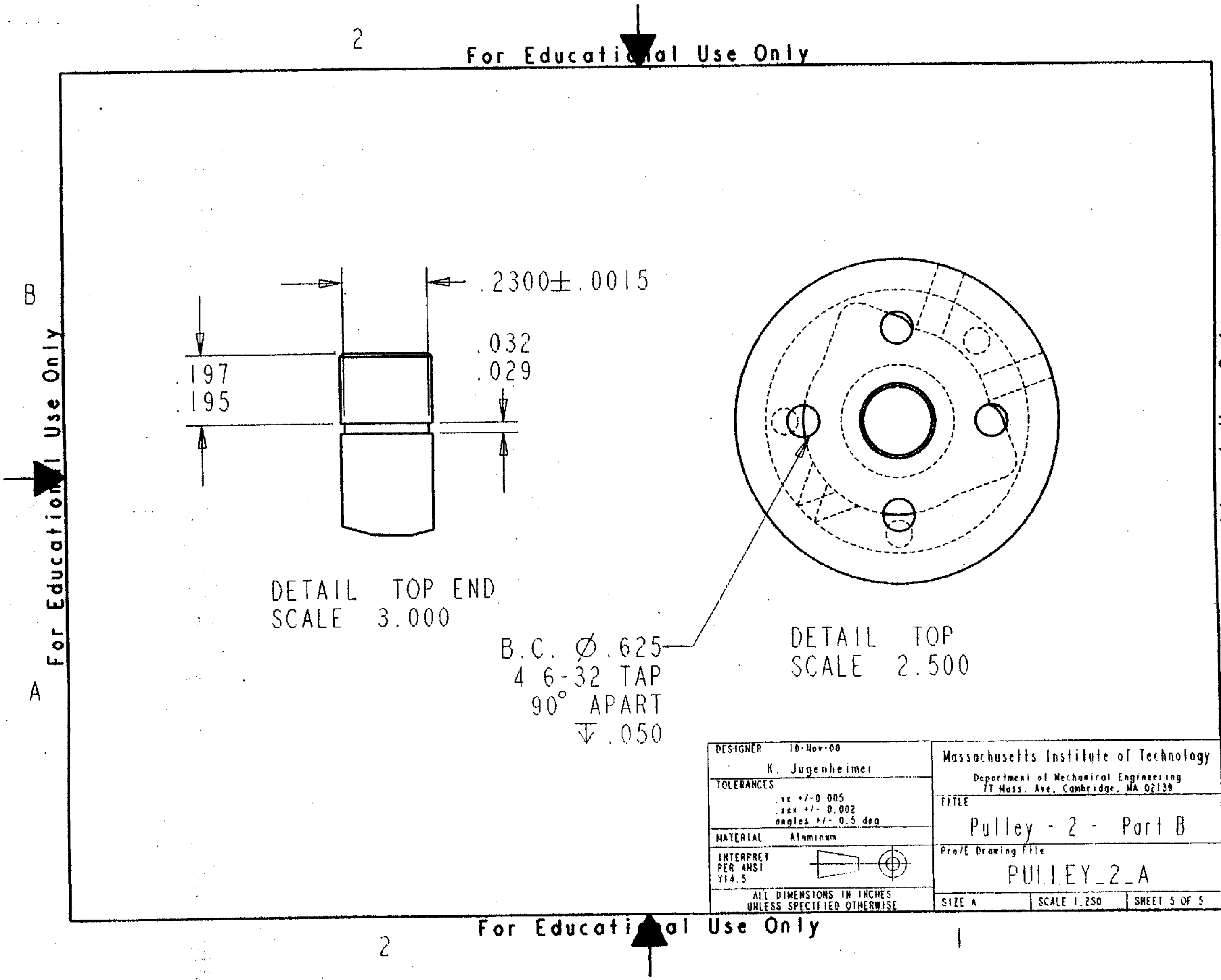
1



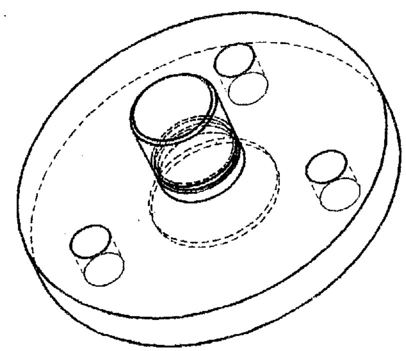
2
For Educational Use Only
SEE DETAIL TOP
.2498
.2494
B
SEE DETAIL TOP END
4.104
SEE DETAIL PULLEY
.480
A
SEE DETAIL BOTTOM
Ø1.075
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 2 - Part B
Pro/E Drawing File
PULLEY_2_A
SIZE A
SCALE 0.750
SHEET 2 OF 5
1


For Educational Use Only
1.075
.875
.205 .110
.170 .240
.155
.060
.120 .190
(ALL DIMENSIONS IN THIS VIEW ARE ±.001)
DETAIL PULLEY
SCALE 2.500
2-56 THRU
2-56 THRU
25.0°
25.0°
SECTION 4-4
SCALE 2.000
SECTION 2-2
SCALE 2.000
DESIGNER 10-Nov-06
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 2 - Part A
Pro/E Drawing File
PULLEY_2_A
SIZE A
SCALE 1.250
SHEET 3 OF 5


For Educational Use Only
2
B
A
Ø.070
SECTION 3-3
SCALE 2.000
25.0°
Ø.070
SECTION 1-1
SCALE 2.000
25.0°
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
45.0°
45.0°
.240
R.313
.241
B.C. Ø.750
3 4-40 TAP
↧.250
.366
.619
DETAIL BOTTOM
SCALE 3.000
R.313
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
xx +/-0.005
xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 2 - Part A
Pro/E Drawing File
PULLEY_2_A
SIZE A
SCALE 1.250
SHEET 4 OF 5
1


For Educational Use Only
2
B
A
.2300±.0015
.197
.195
.032
.029
DETAIL TOP END
SCALE 3.000
B.C. Ø.625
4 6-32 TAP
90° APART
↧.050
DETAIL TOP
SCALE 2.500
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 2 - Part B
Pro/E Drawing File
PULLEY_2_A
SIZE A
SCALE 1.250
SHEET 5 OF 5
1

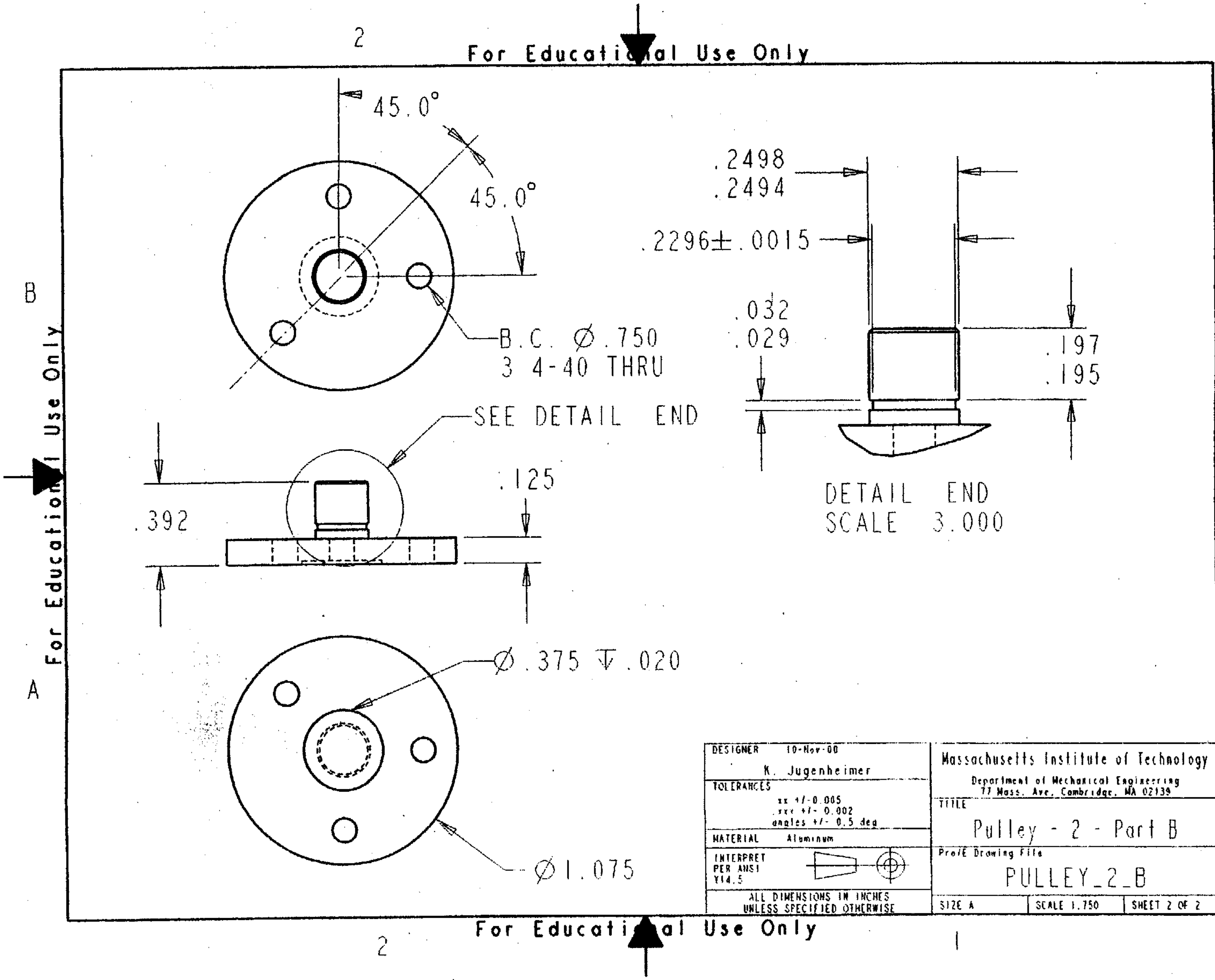
11-10-00



ISOMETRIC VIEW

DESIGNER 10-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 2 - Part B
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_2_B
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.500 | SHEET 1 OF 2

For Educational Use Only

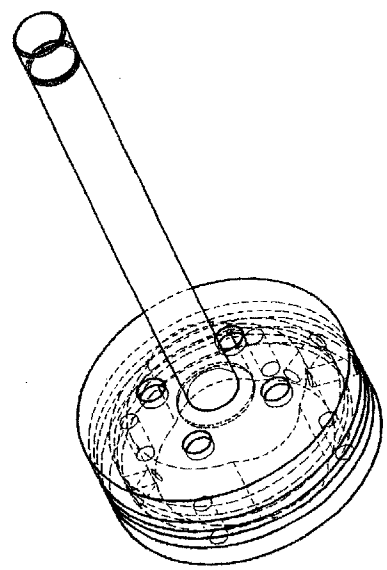

For Educational Use Only
45.0°
45.0°
B.C. Ø.750
3 4-40 THRU
SEE DETAIL END
.392
.125
Ø.375 ↧.020
Ø1.075
.2498
.2494
.2296±.0015
.032
.029
.197
.195
DETAIL END
SCALE 3.000
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Pulley - 2 - Part B
Pro/E Drawing File
PULLEY_2_B
SIZE A
SCALE 1.750
SHEET 2 OF 2

11-10-00

2

B

E



ISOMETRIC VIEW

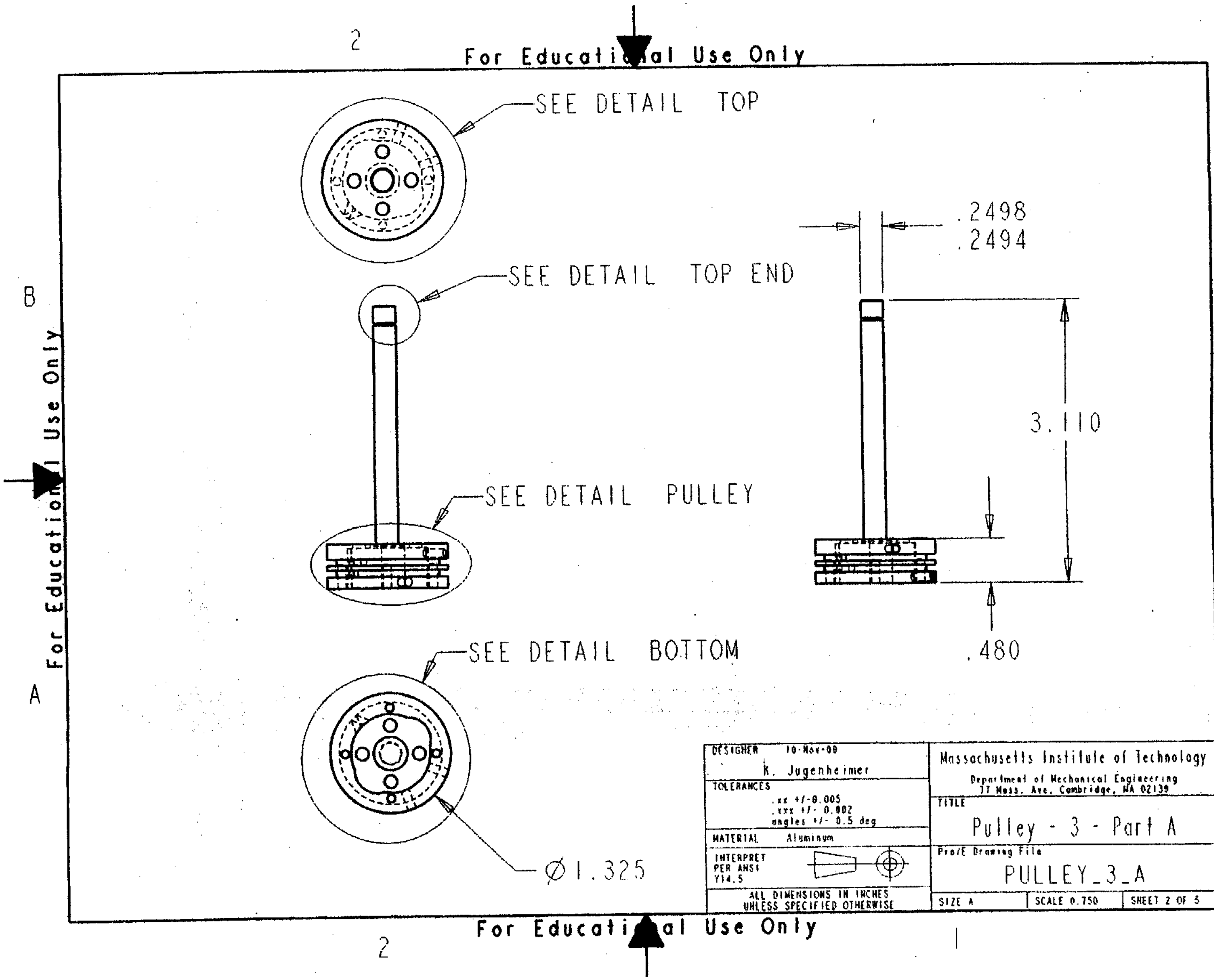
A

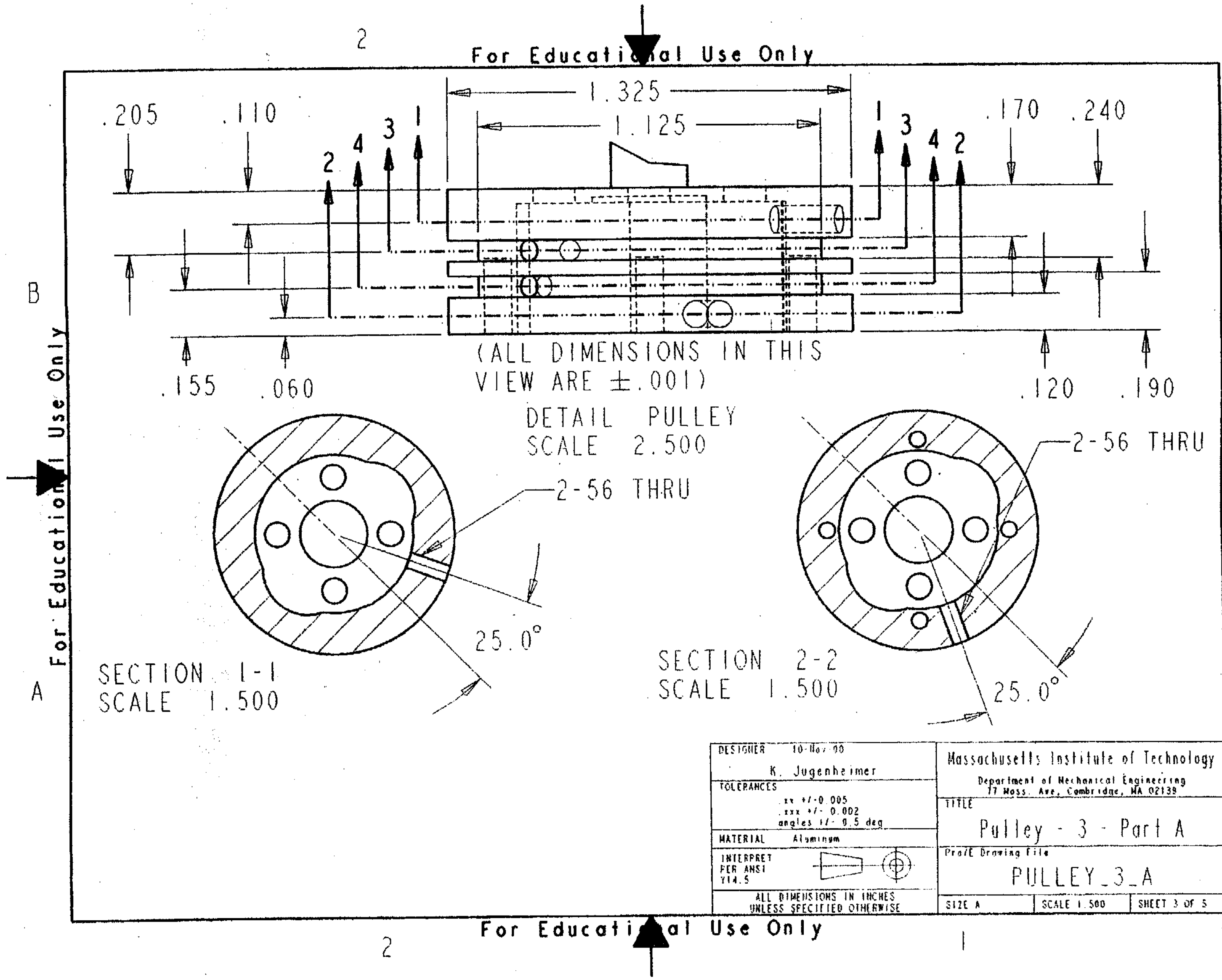
DESIGNER 10-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES xx +/-0.005 xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 3 - Part A
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_3_A
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 1.500 · SHEET 1 OF 5

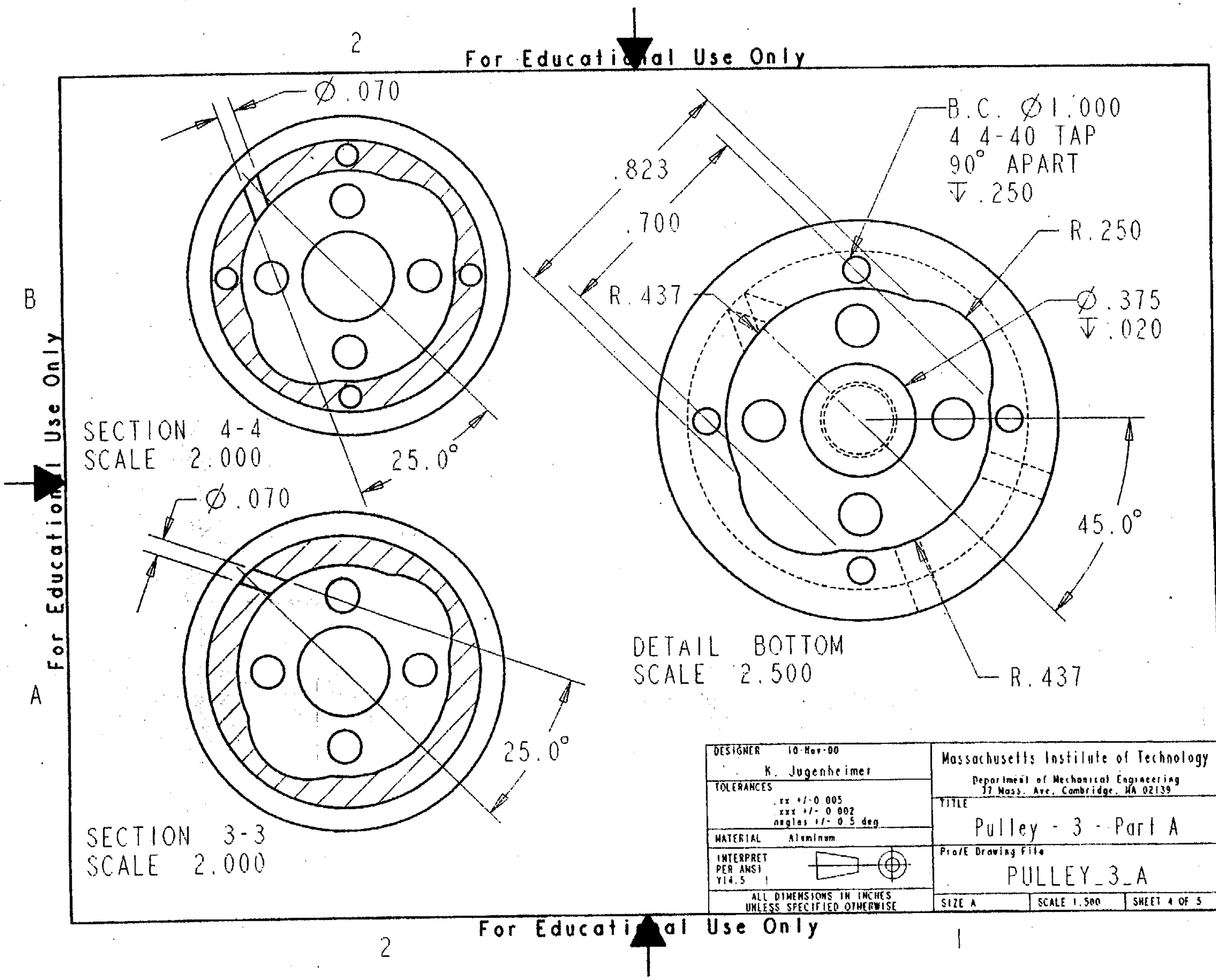
For Educational Use Only

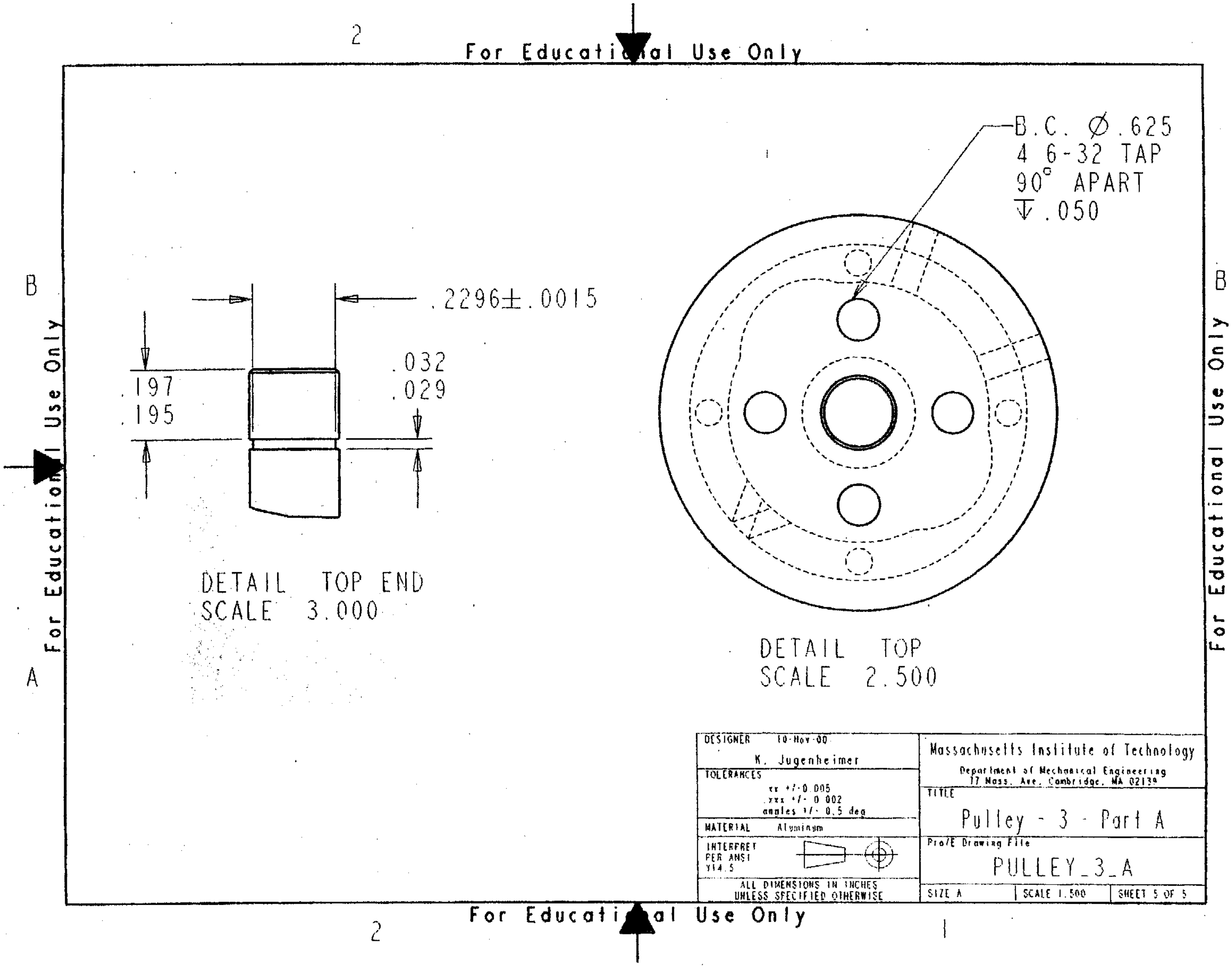
2

1


For Educational Use Only
SEE DETAIL TOP
SEE DETAIL TOP END
SEE DETAIL PULLEY
SEE DETAIL BOTTOM
.2498
.2494
3.110
.480
Ø1.325
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Pulley - 3 - Part A
Pro/E Drawing File
PULLEY_3_A
SIZE A
SCALE 0.750
SHEET 2 OF 5


For Educational Use Only
1.325
1.125
.205
.110
.170
.240
(ALL DIMENSIONS IN THIS
VIEW ARE ±.001)
.155
.060
.120
.190
DETAIL PULLEY
SCALE 2.500
2-56 THRU
25.0°
SECTION 1-1
SCALE 1.500
SECTION 2-2
SCALE 1.500
2-56 THRU
25.0°
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES
UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 3 - Part A
Pro/E Drawing File
PULLEY_3_A
SIZE A
SCALE 1.500
SHEET 3 OF 5
For Educational Use Only


For Educational Use Only
Ø.070
SECTION 4-4
SCALE 2.000
25.0°
Ø.070
25.0°
SECTION 3-3
SCALE 2.000
.823
.700
R.437
B.C. Ø1.000
4 4-40 TAP
90° APART
↧.250
R.250
Ø.375
↧.020
45.0°
DETAIL BOTTOM
SCALE 2.500
R.437
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/-0.002
angles +/-0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Pulley - 3 - Part A
Pro/E Drawing File
PULLEY_3_A
SIZE A
SCALE 1.500
SHEET 4 OF 5


For Educational Use Only
2
B
A
.2296±.0015
.197
.195
.032
.029
DETAIL TOP END
SCALE 3.000
B.C. Ø.625
4 6-32 TAP
90° APART
↧.050
DETAIL TOP
SCALE 2.500
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Pulley - 3 - Part A
Pro/E Drawing File
PULLEY_3_A
SIZE A
SCALE 1.500
SHEET 5 OF 5
1

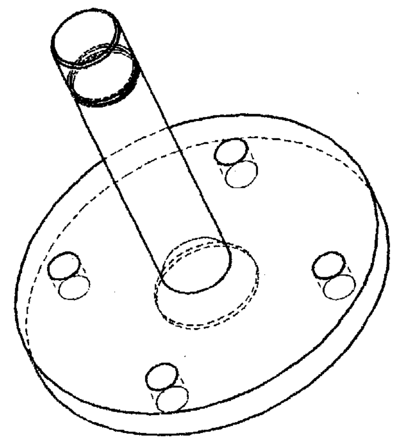
11-10-00

2

For Educational Use Only

B

For Educational Use Only



ISOMETRIC VIEW

A

B

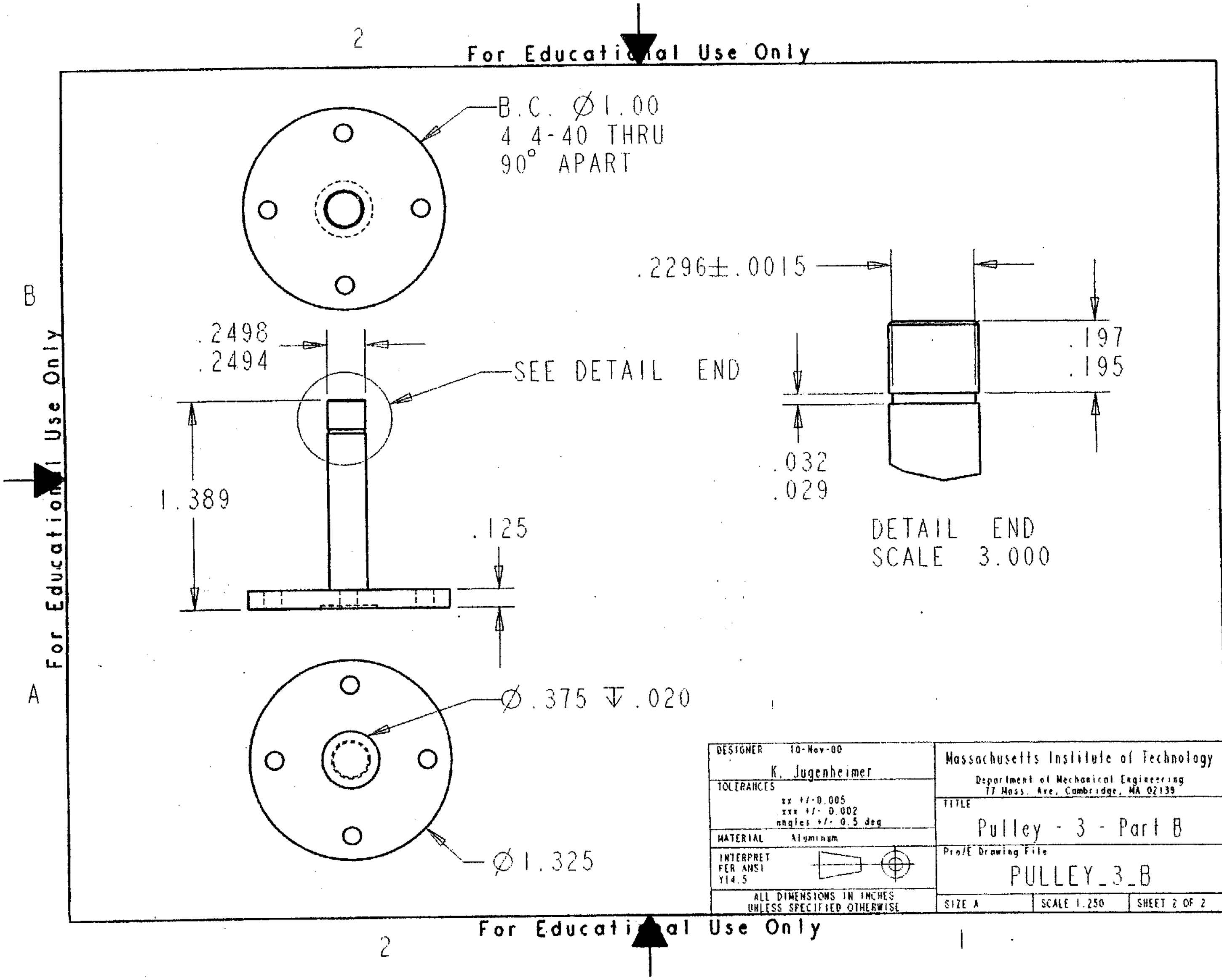
For Educational Use Only

DESIGNER 10-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 3 - Part B
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_3_B
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 2

For Educational Use Only

2

1



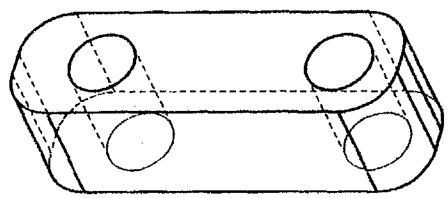
For Educational Use Only
B.C. Ø1.00
4 4-40 THRU
90° APART
.2296±.0015
.2498
.2494
SEE DETAIL END
1.389
.125
.197
.195
.032
.029
DETAIL END
SCALE 3.000
Ø.375 ↧.020
Ø1.325
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
xx +/-0.005
xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 3 - Part B
Pro/E Drawing File
PULLEY_3_B
SIZE A
SCALE 1.250
SHEET 2 OF 2

2

B

For Educational Use Only

For Educational Use Only



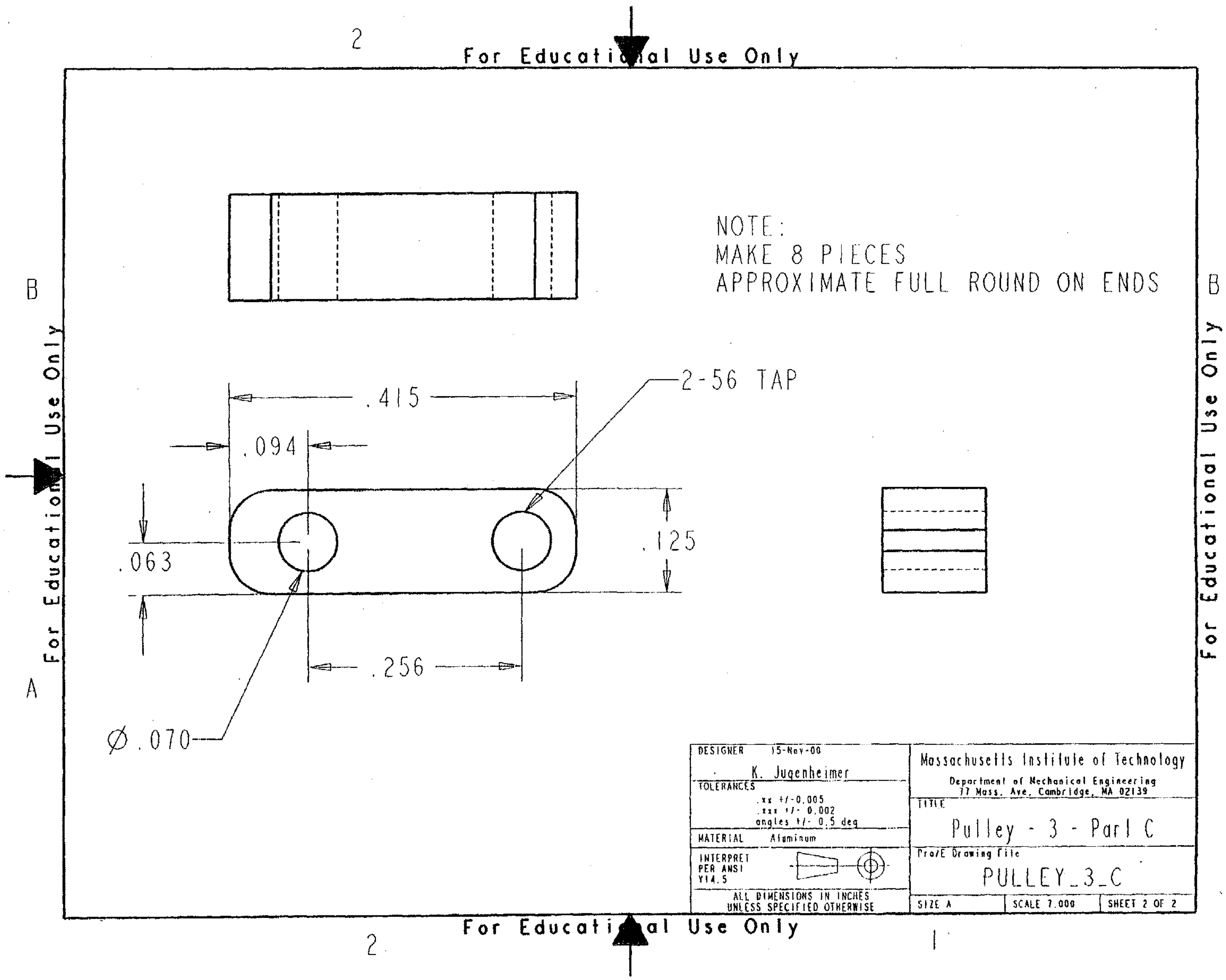
ISOMETRIC VIEW

A

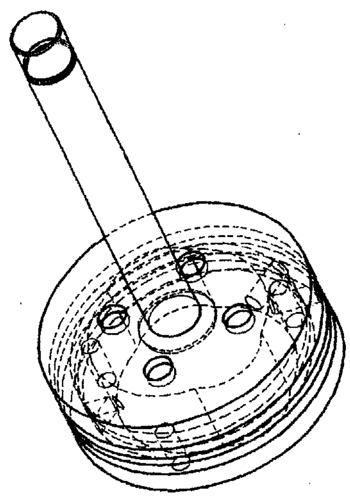
DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 3 - Part C
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_3_C
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 1.000 / SHEET 1 OF 2

For Educational Use Only

2 1


For Educational Use Only
NOTE:
MAKE 8 PIECES
APPROXIMATE FULL ROUND ON ENDS
2-56 TAP
.415
.094
.063
.125
.256
Ø.070
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 3 - Part C
Pro/E Drawing File
PULLEY_3_C
SIZE A
SCALE 7.000
SHEET 2 OF 2

11-14-00



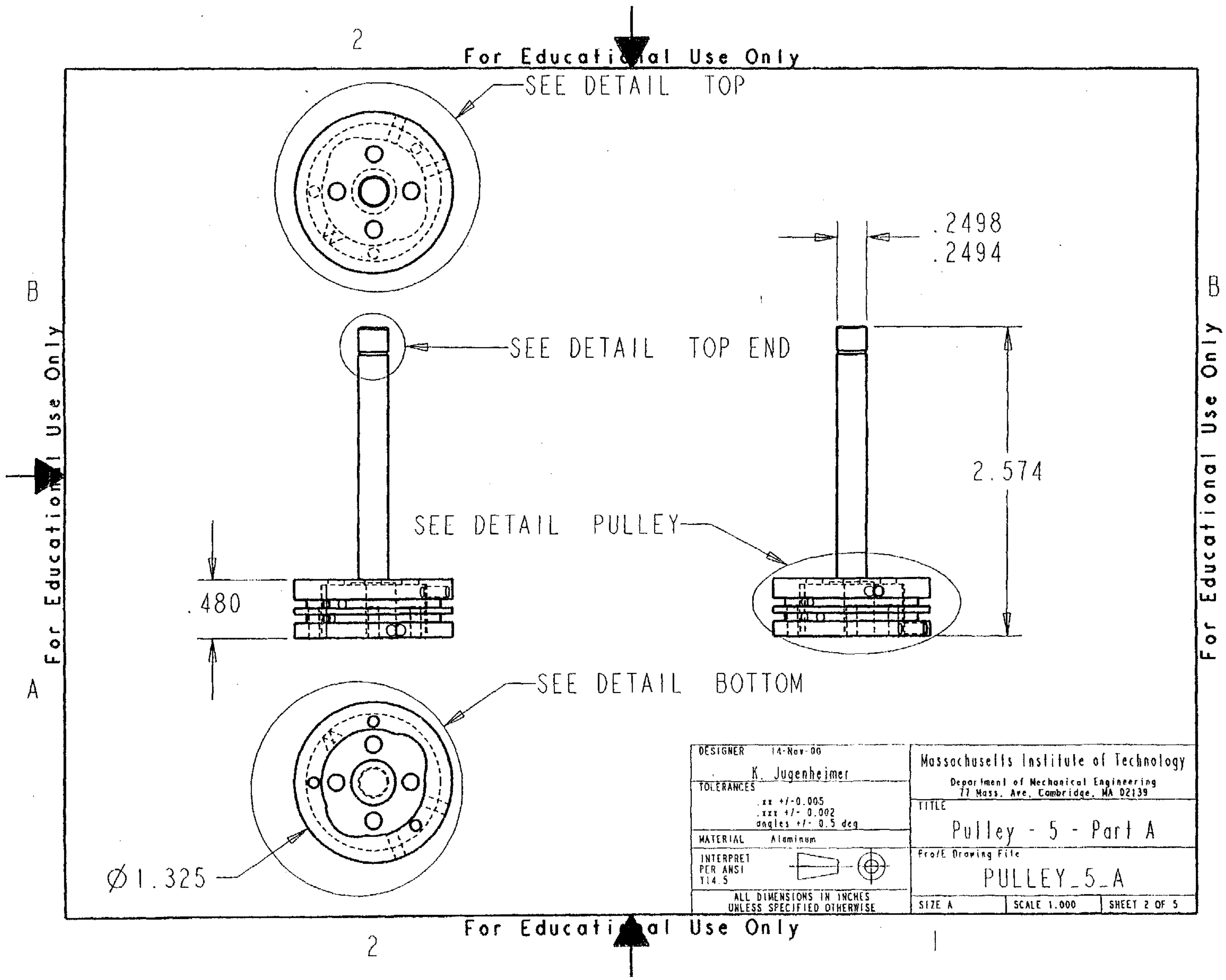
ISOMETRIC VIEW

DESIGNER: 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 5 - Part A
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_5_A
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.500 | SHEET 1 OF 5

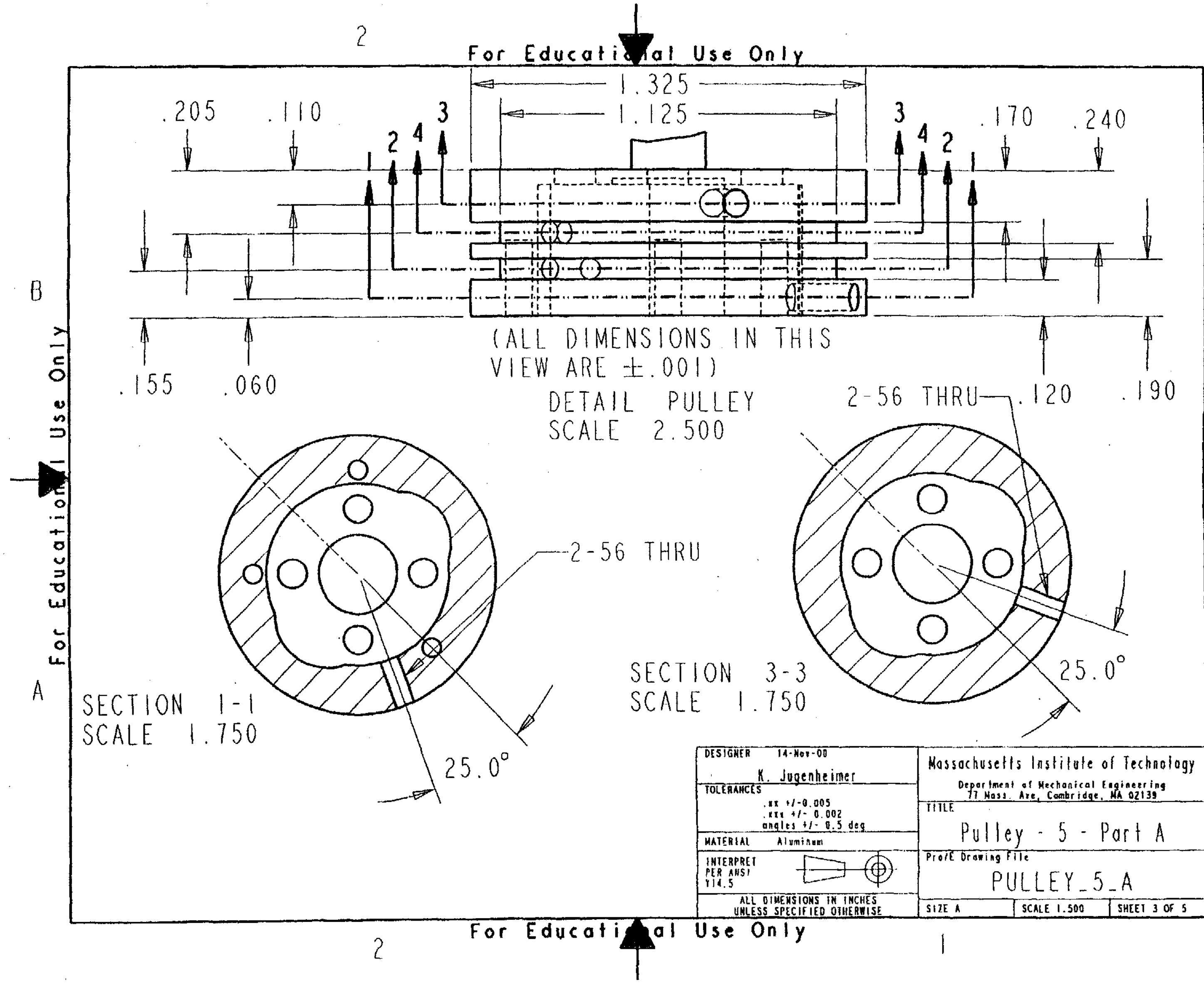
For Educational Use Only

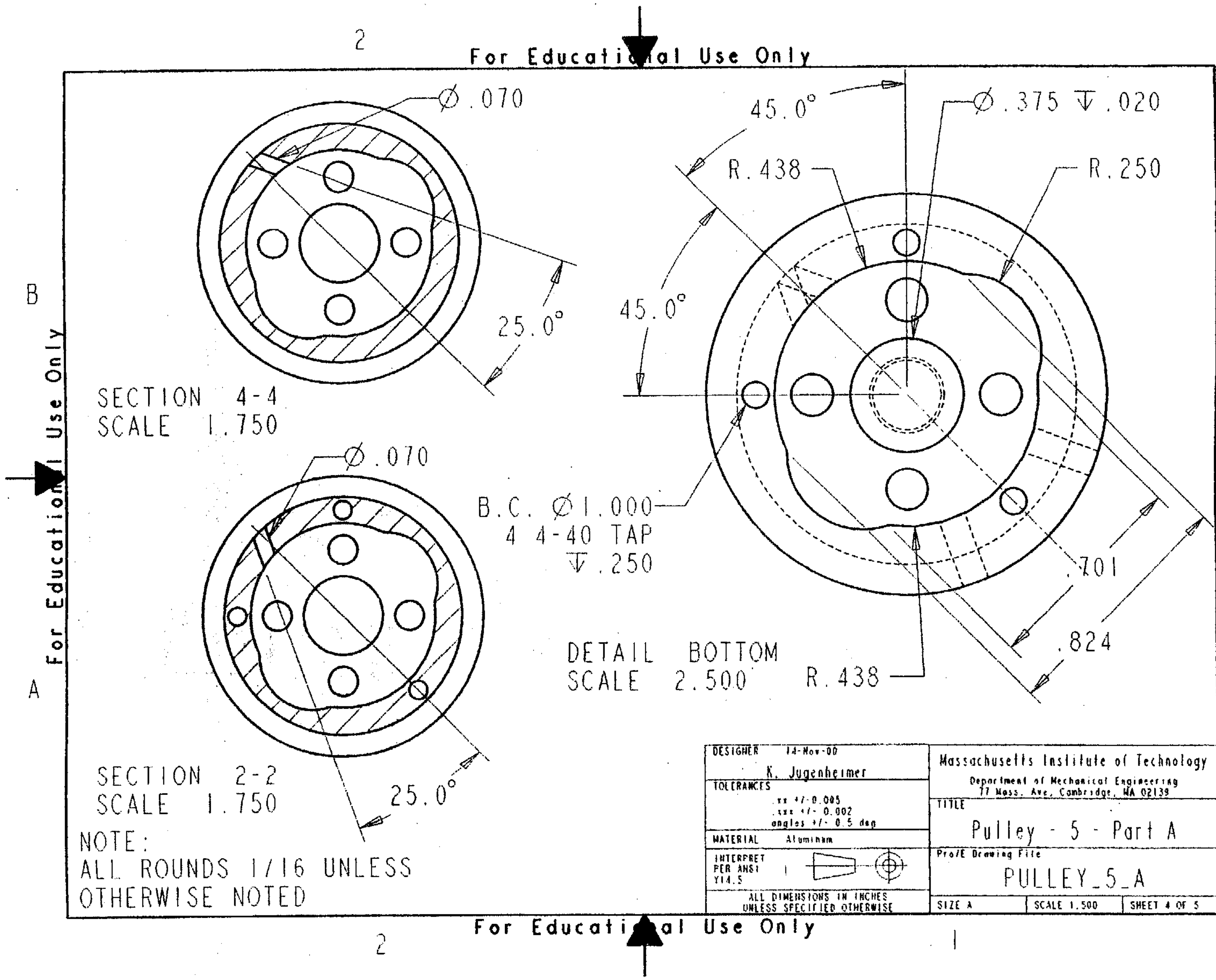
For Educational Use Only

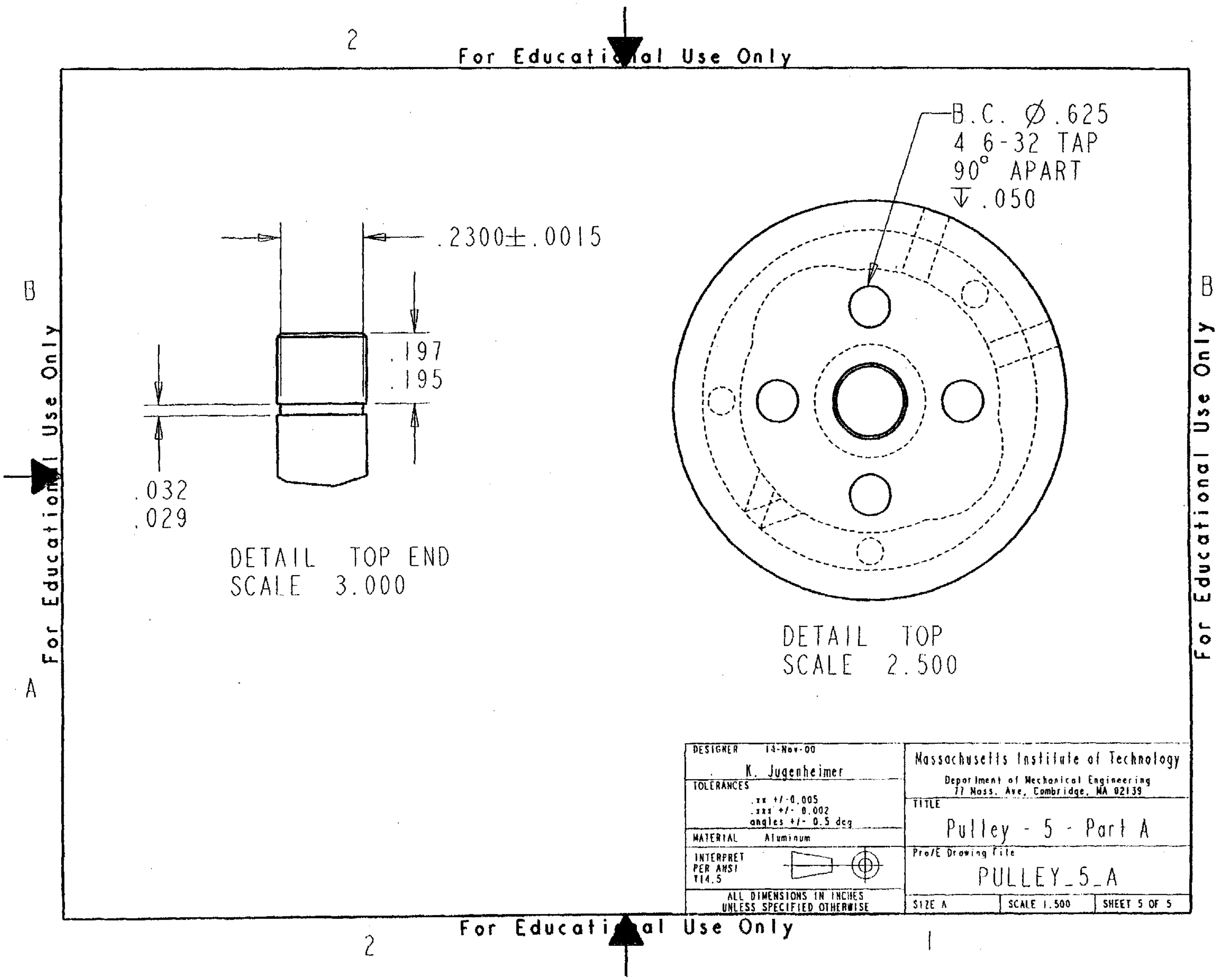
For Educational Use Only



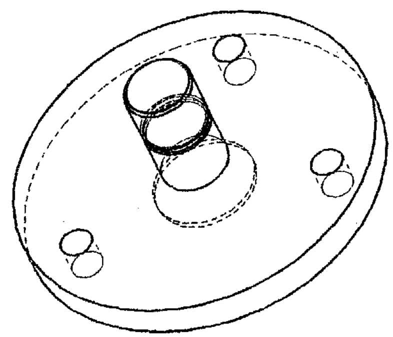
For Educational Use Only
SEE DETAIL TOP
SEE DETAIL TOP END
.2498
.2494
2.574
SEE DETAIL PULLEY
.480
SEE DETAIL BOTTOM
Ø1.325
DESIGNER 14-Nov-06
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Pulley - 5 - Part A
Pro/E Drawing File
PULLEY_5_A
SIZE A
SCALE 1.000
SHEET 2 OF 5


For Educational Use Only
1.325
1.125
.205
.110
.170
.240
.155
.060
.120
.190
(ALL DIMENSIONS IN THIS VIEW ARE ±.001)
DETAIL PULLEY
SCALE 2.500
2-56 THRU
SECTION 1-1
SCALE 1.750
SECTION 3-3
SCALE 1.750
25.0°
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 5 - Part A
Pro/E Drawing File
PULLEY_5_A
SIZE A
SCALE 1.500
SHEET 3 OF 5


For Educational Use Only
Ø.070
25.0°
SECTION 4-4
SCALE 1.750
Ø.070
25.0°
SECTION 2-2
SCALE 1.750
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
45.0°
Ø.375 ⟂ .020
R.438
R.250
45.0°
B.C. Ø1.000
4 4-40 TAP
⟂ .250
.701
.824
DETAIL BOTTOM
SCALE 2.500
R.438
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Pulley - 5 - Part A
Pro/E Drawing File
PULLEY_5_A
SIZE A
SCALE 1.500
SHEET 4 OF 5
For Educational Use Only
2
B
A
1


For Educational Use Only
B.C. Ø.625
4 6-32 TAP
90° APART
↧.050
.2300±.0015
.197
.195
.032
.029
DETAIL TOP END
SCALE 3.000
DETAIL TOP
SCALE 2.500
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 5 - Part A
Pro/E Drawing File
PULLEY_5_A
SIZE A
SCALE 1.500
SHEET 5 OF 5

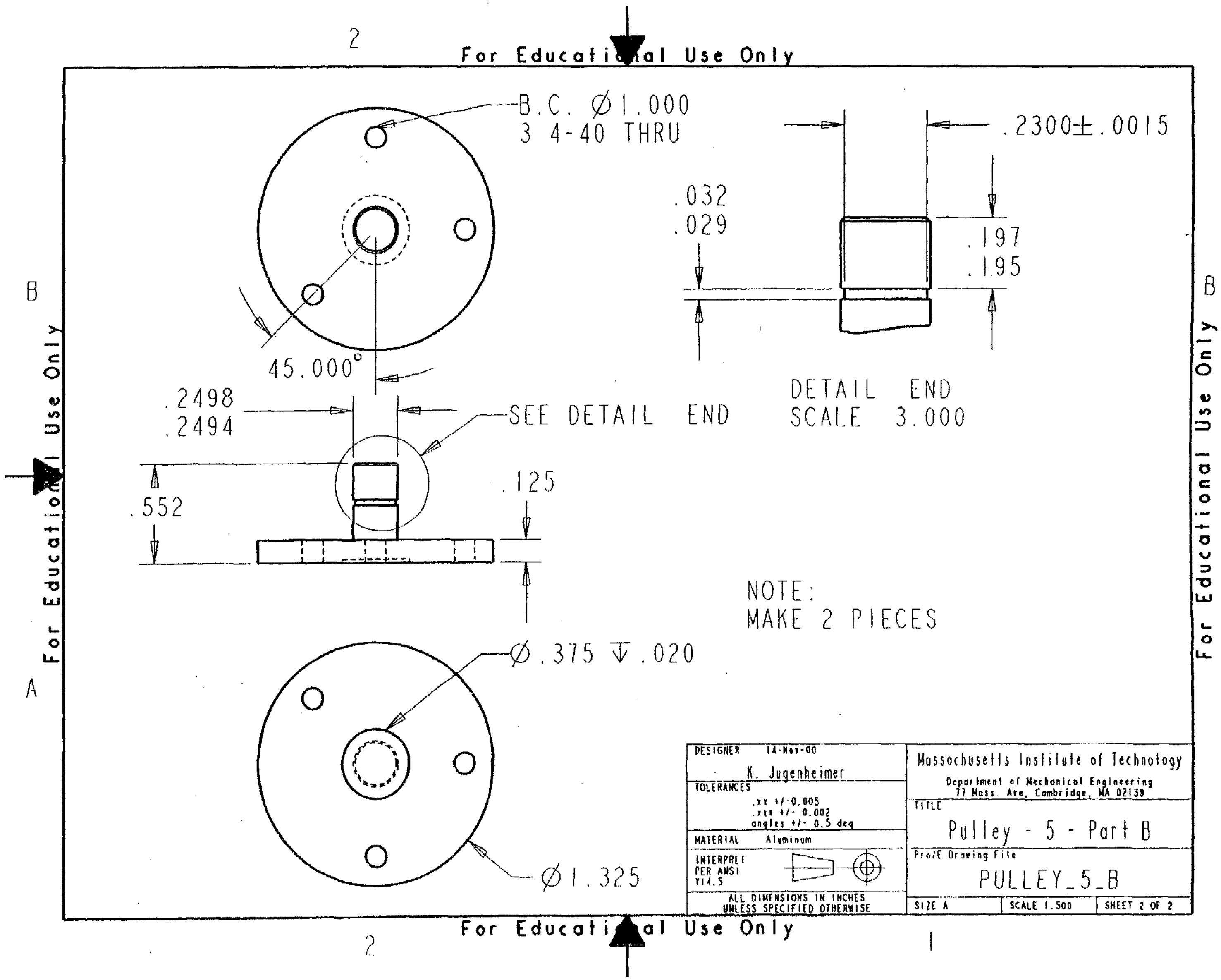
11-14-00



ISOMETRIC VIEW

DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 5 - Part B
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_5_B
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 2

For Educational Use Only
For Educational Use Only
For Educational Use Only


For Educational Use Only
B.C. Ø1.000
3 4-40 THRU
.2300±.0015
.032
.029
.197
.195
45.000°
.2498
.2494
SEE DETAIL END
DETAIL END
SCALE 3.000
.552
.125
NOTE:
MAKE 2 PIECES
Ø.375 ↧ .020
Ø1.325
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 5 - Part B
Pro/E Drawing File
PULLEY_5_B
SIZE A
SCALE 1.500
SHEET 2 OF 2

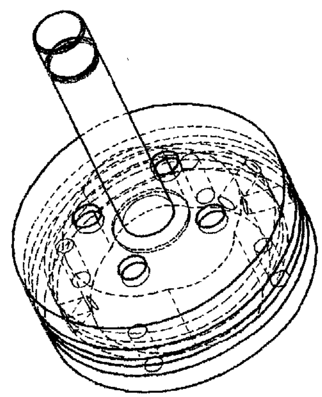
11-14-00

2

For Educational Use Only

B

For Educational Use Only



ISOMETRIC VIEW

A

B

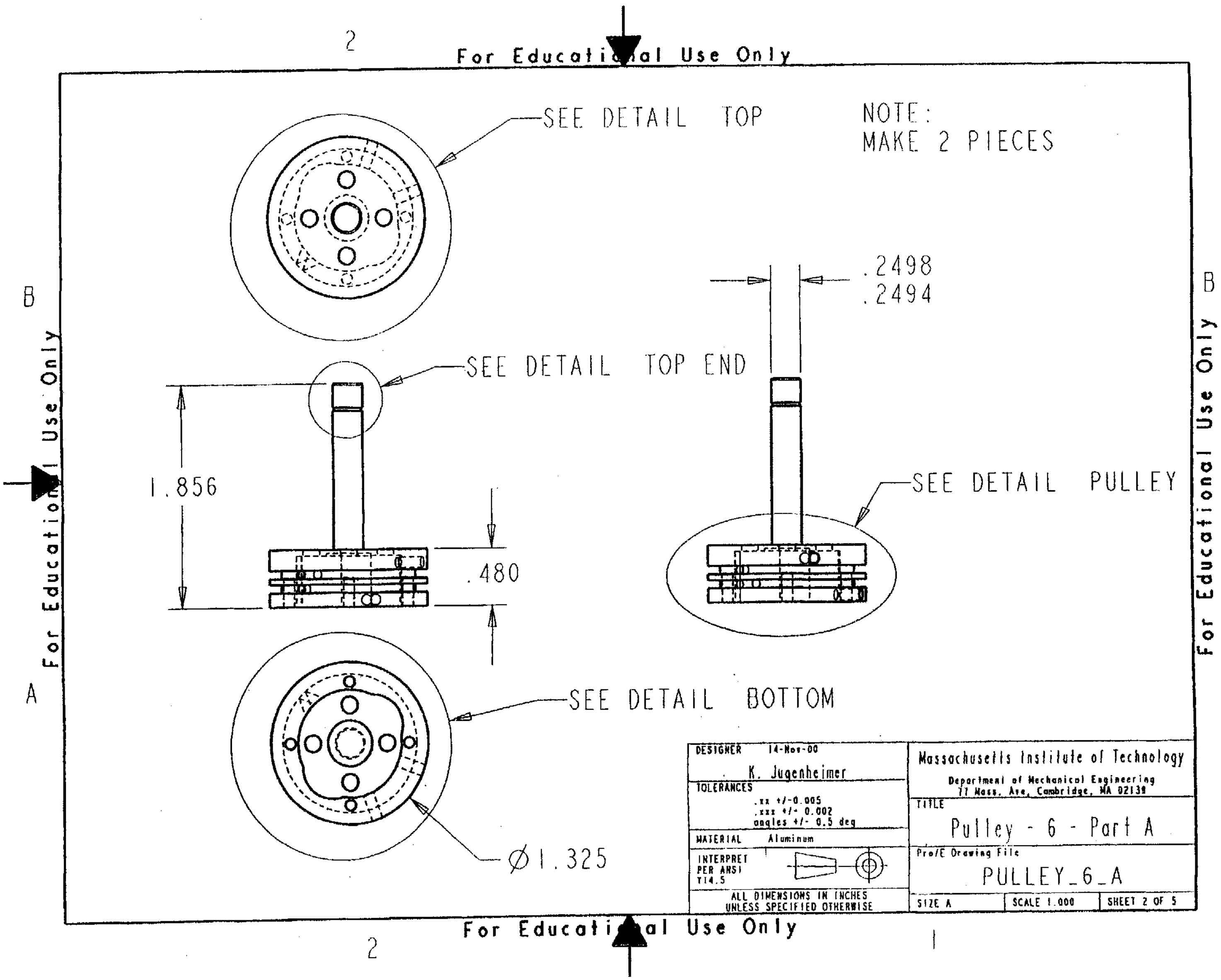
For Educational Use Only

262

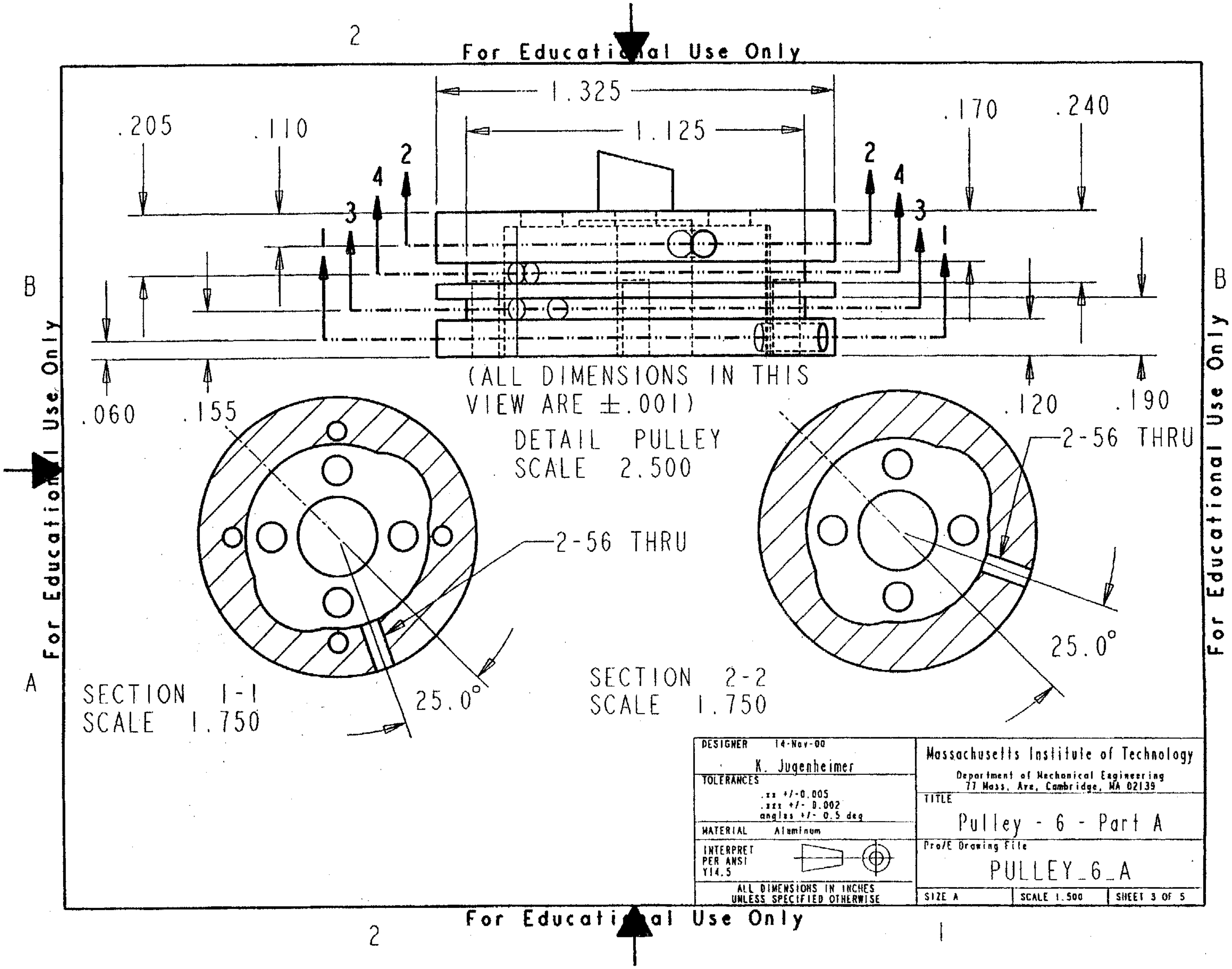
DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 6 - Part A
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_6_A
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 1.500 / SHEET 1 OF 5

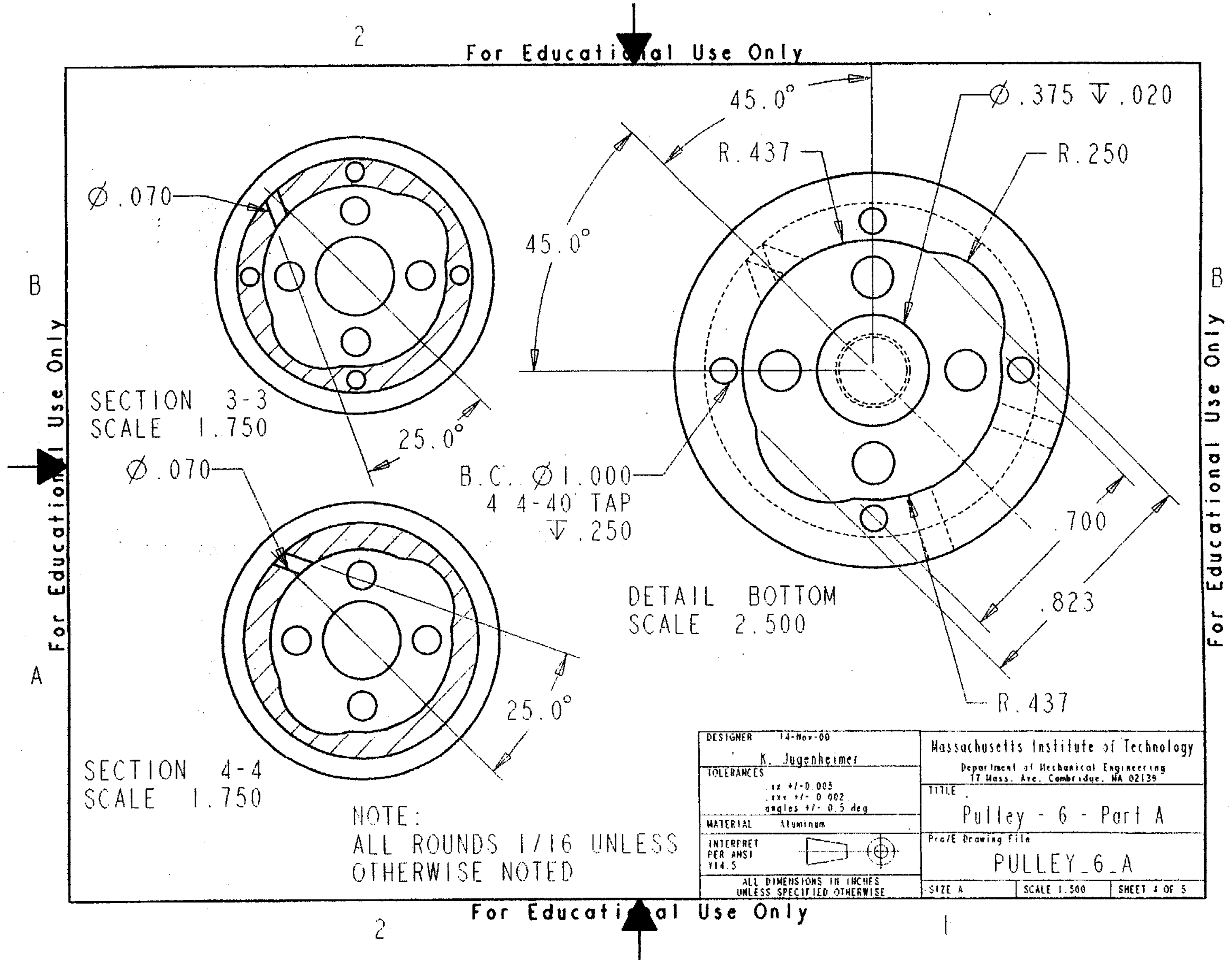
For Educational Use Only

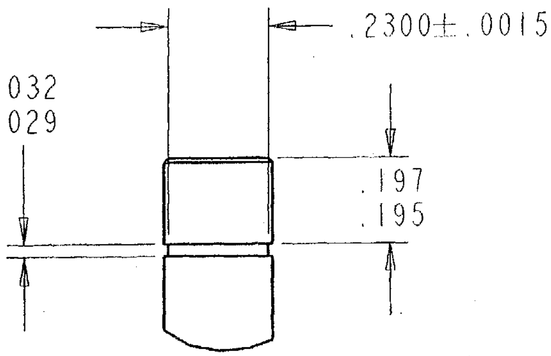
2 1



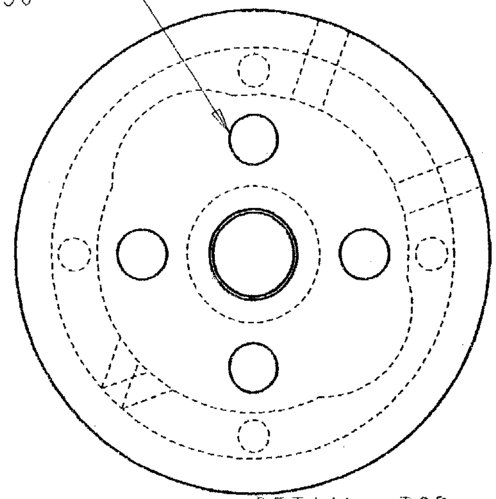
2
For Educational Use Only
SEE DETAIL TOP
NOTE:
MAKE 2 PIECES
B
.2498
.2494
SEE DETAIL TOP END
1.856
SEE DETAIL PULLEY
.480
A
SEE DETAIL BOTTOM
Ø1.325
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 6 - Part A
Pro/E Drawing File
PULLEY_6_A
SIZE A
SCALE 1.000
SHEET 2 OF 5
1


For Educational Use Only
1.325
1.125
.205
.110
.170
.240
.060
.155
.120
.190
(ALL DIMENSIONS IN THIS VIEW ARE ±.001)
DETAIL PULLEY
SCALE 2.500
2-56 THRU
2-56 THRU
25.0°
25.0°
SECTION 1-1
SCALE 1.750
SECTION 2-2
SCALE 1.750
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 6 - Part A
Pro/E Drawing File
PULLEY_6_A
SIZE A
SCALE 1.500
SHEET 3 OF 5


For Educational Use Only
2
B
A
Ø.070
SECTION 3-3
SCALE 1.750
25.0°
Ø.070
SECTION 4-4
SCALE 1.750
25.0°
45.0°
45.0°
R.437
Ø.375 ↧.020
R.250
B.C. Ø1.000
4 4-40 TAP
↧.250
.700
.823
R.437
DETAIL BOTTOM
SCALE 2.500
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Pulley - 6 - Part A
Pro/E Drawing File
PULLEY_6_A
SIZE A
SCALE 1.500
SHEET 4 OF 5
1



DETAIL TOP END
SCALE 3.000



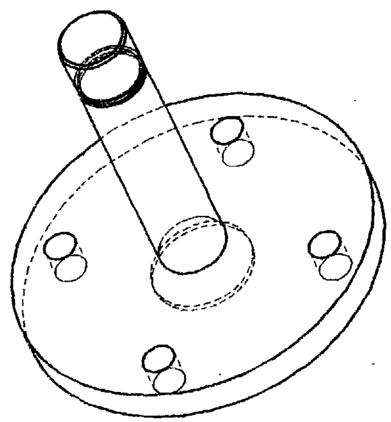
DETAIL TOP
SCALE 2.500

DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 6 - Part A
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_6_A
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.500 | SHEET 5 OF 5

For Educational Use Only

11-14-00

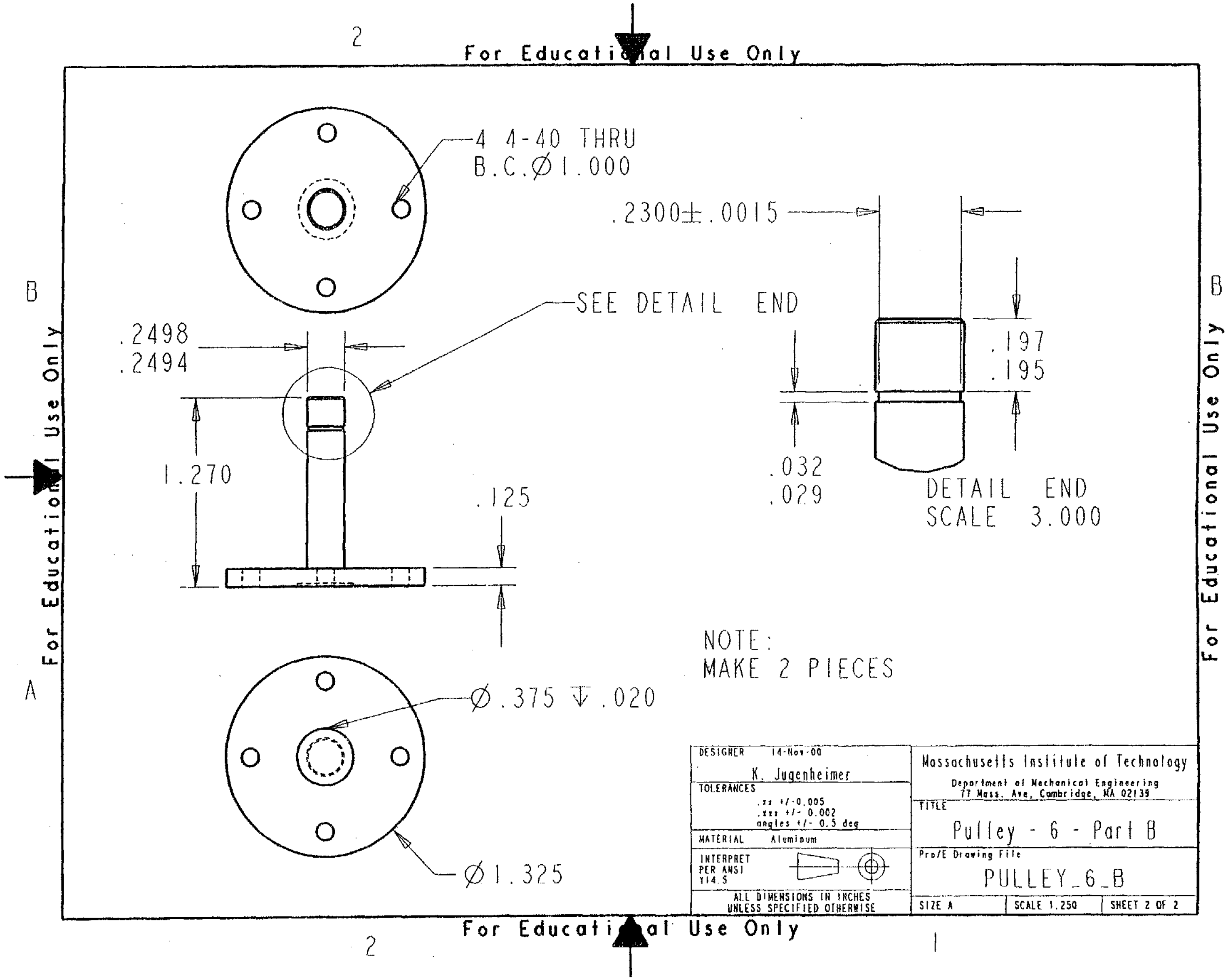
For Educational Use Only



ISOMETRIC VIEW

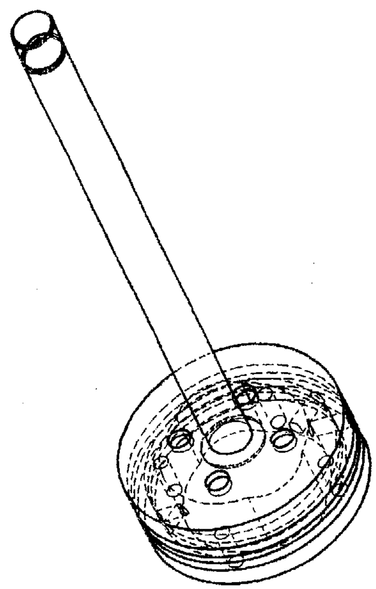
DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 6 - Part B
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_6_B
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 2

For Educational Use Only



For Educational Use Only
4 4-40 THRU
B.C.Ø1.000
.2300±.0015
SEE DETAIL END
.2498
.2494
.197
.195
1.270
.125
.032
.029
DETAIL END
SCALE 3.000
NOTE:
MAKE 2 PIECES
Ø.375 ↧.020
Ø1.325
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 6 - Part B
Pro/E Drawing File
PULLEY_6_B
SIZE A
SCALE 1.250
SHEET 2 OF 2

11-10-00



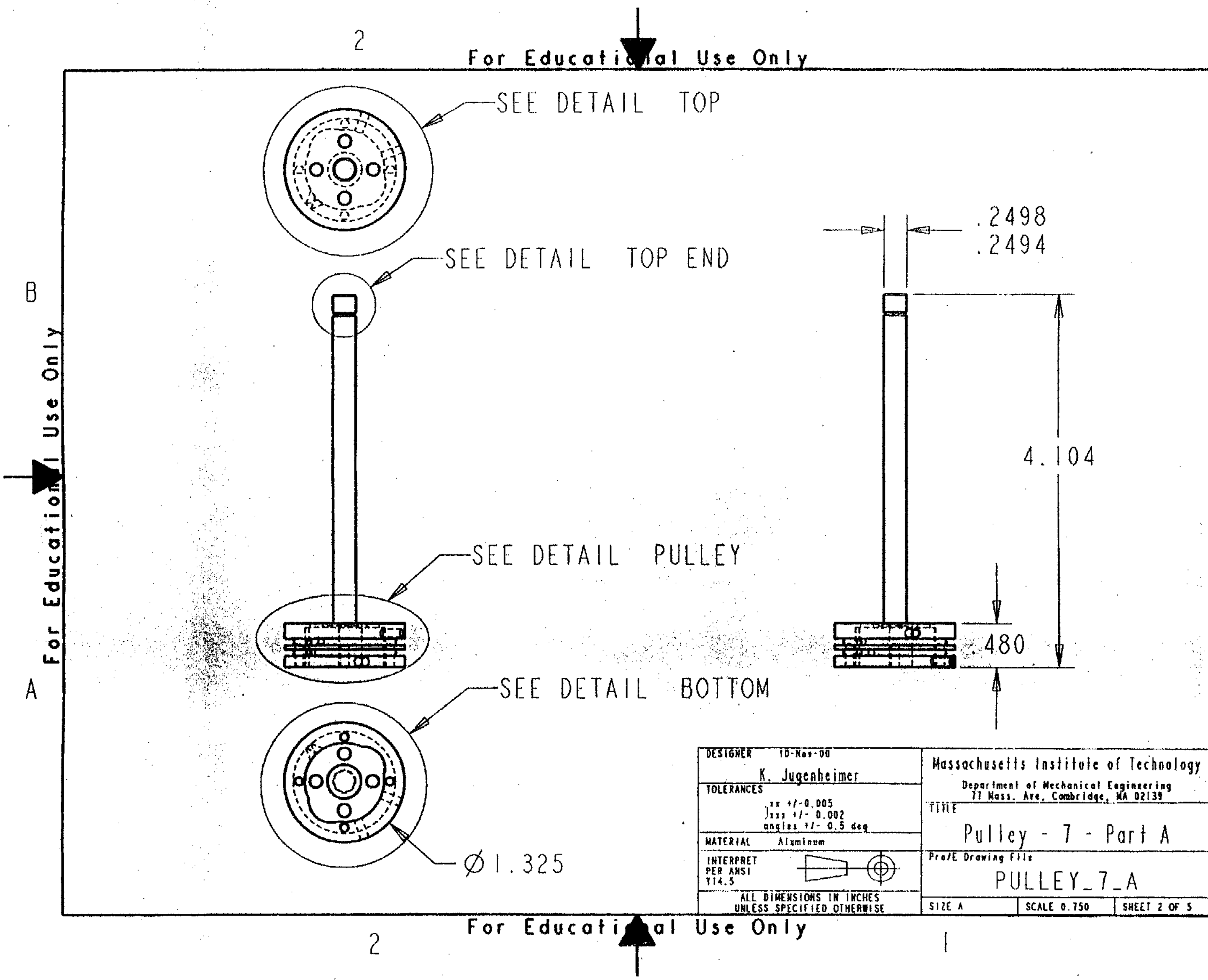
ISOMETRIC VIEW

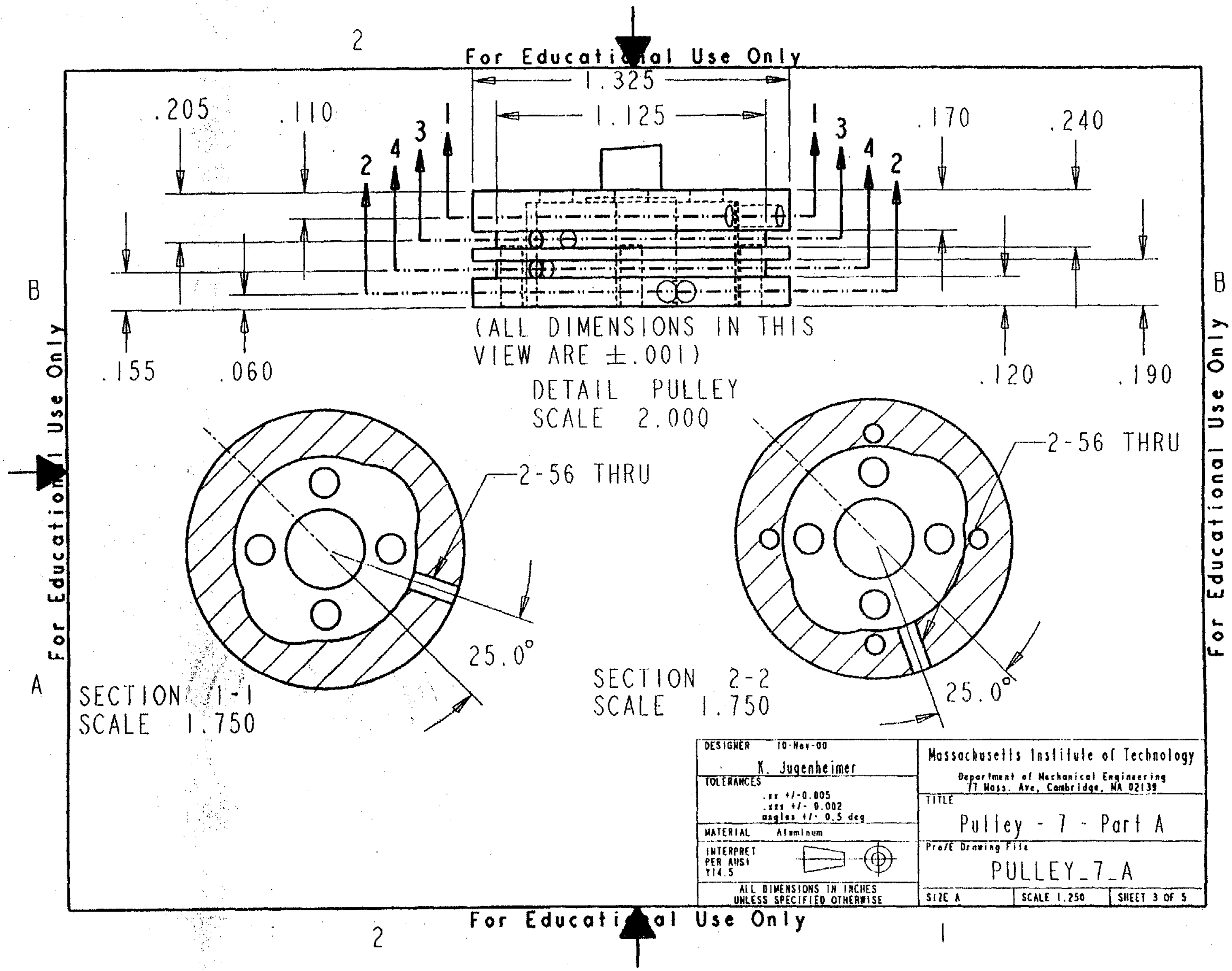
DESIGNER 10-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave., Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 7 - Part A
MATERIAL Aluminum	ProE Drawing File PULLEY_7_A
INTERPRET PER ANSI Y14.5	
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.250 | SHEET 1 OF 5

For Educational Use Only

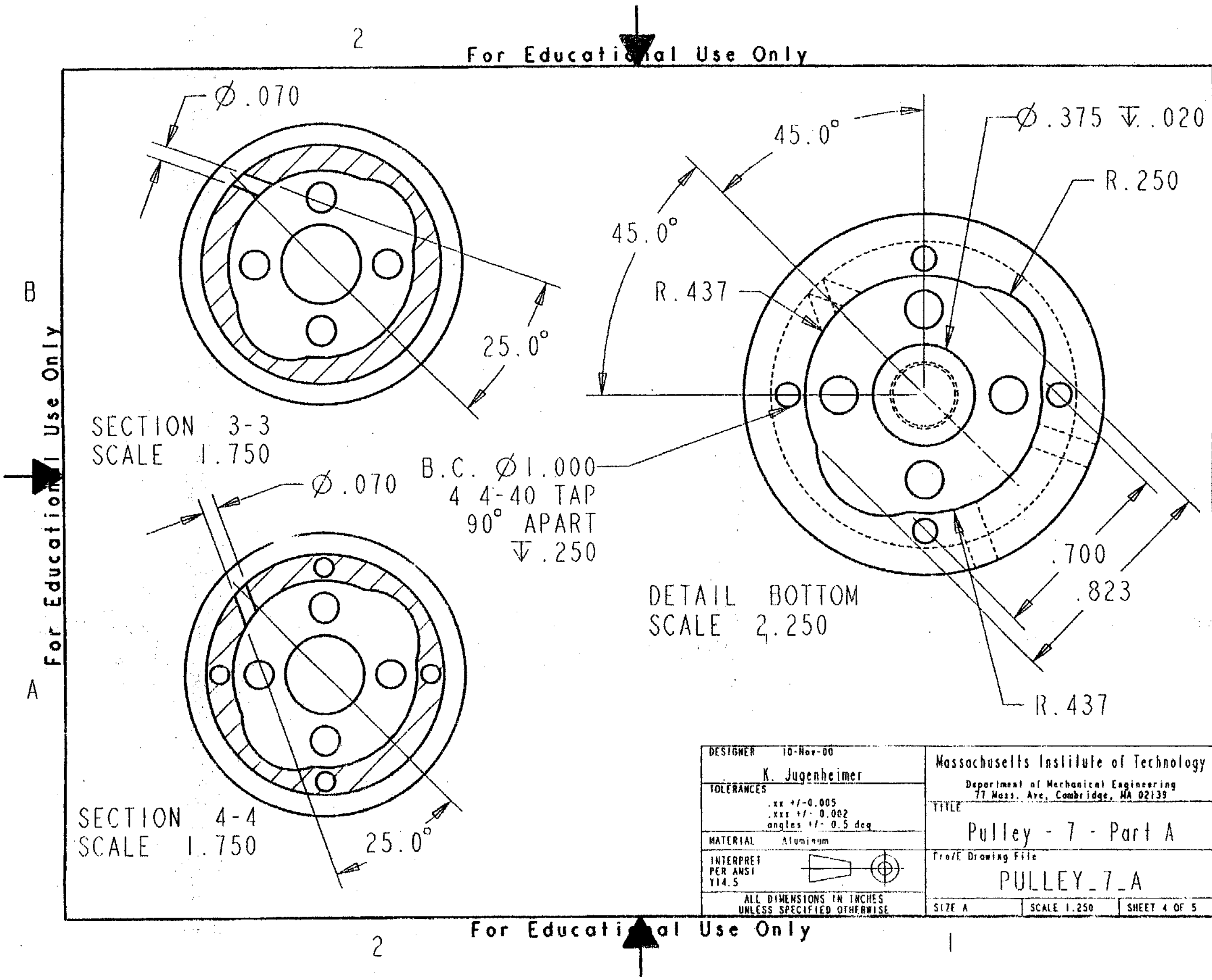
For Educational Use Only

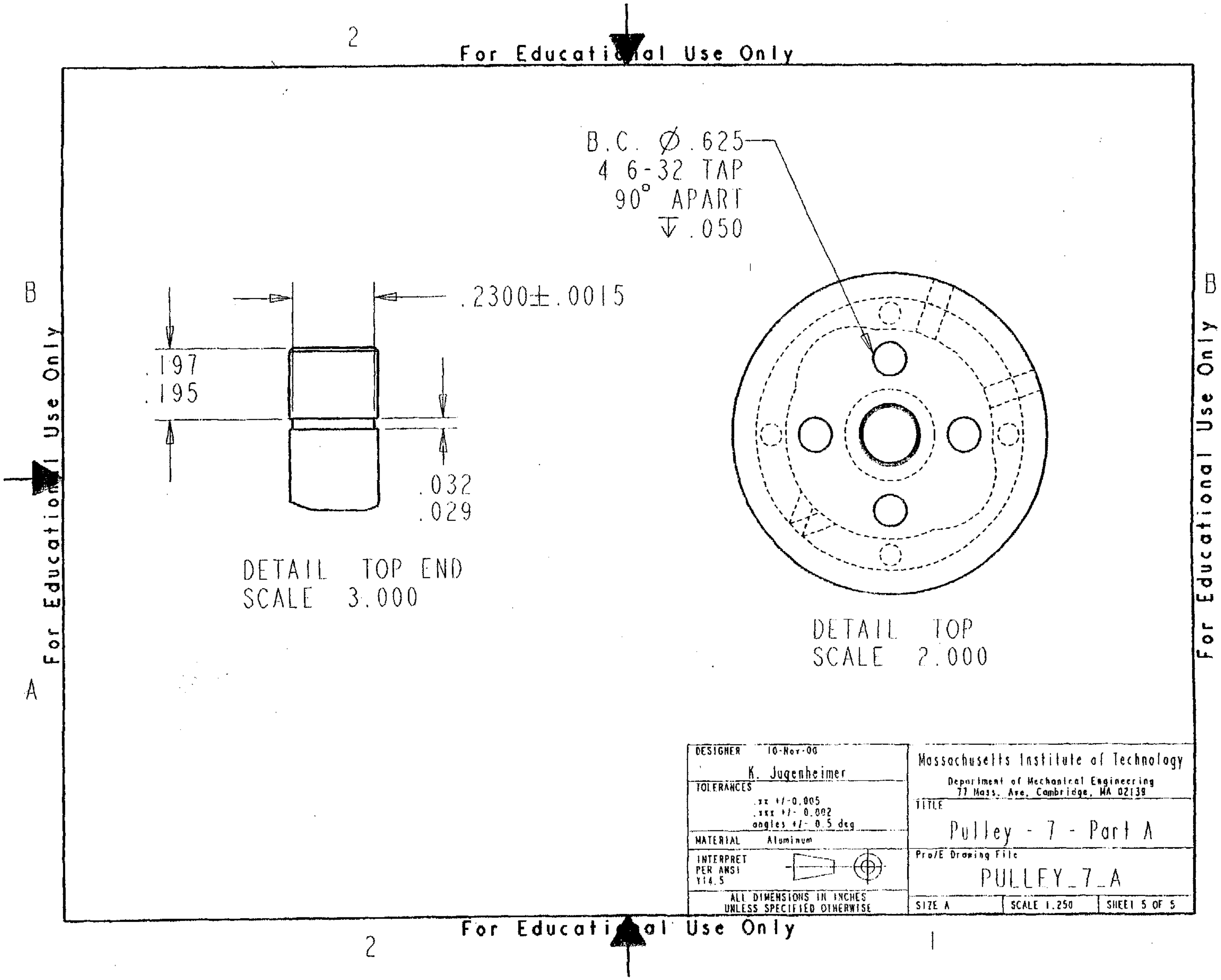
For Educational Use Only


2
For Educational Use Only
SEE DETAIL TOP
SEE DETAIL TOP END
.2498
.2494
B
B
For Educational Use Only
For Educational Use Only
4.104
SEE DETAIL PULLEY
.480
A
SEE DETAIL BOTTOM
Ø1.325
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 7 - Part A
Pro/E Drawing File
PULLEY_7_A
SIZE A
SCALE 0.750
SHEET 2 OF 5
For Educational Use Only
2
1



For Educational Use Only
1.325
1.125
.205
.110
.170
.240
.155
.060
.120
.190
(ALL DIMENSIONS IN THIS VIEW ARE ±.001)
DETAIL PULLEY
SCALE 2.000
2-56 THRU
25.0°
SECTION 1-1
SCALE 1.750
SECTION 2-2
SCALE 1.750
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 7 - Part A
Pro/E Drawing File
PULLEY_7_A
SIZE A
SCALE 1.250
SHEET 3 OF 5

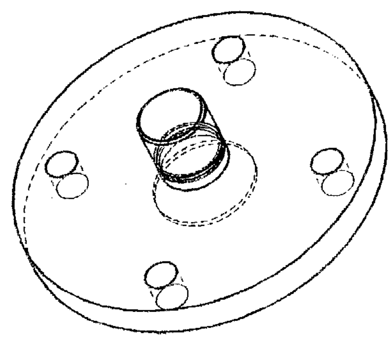

For Educational Use Only
Ø.070
25.0°
SECTION 3-3
SCALE 1.750
Ø.070
25.0°
SECTION 4-4
SCALE 1.750
45.0°
45.0°
Ø.375 ↧.020
R.250
R.437
B.C. Ø1.000
4 4-40 TAP
90° APART
↧.250
DETAIL BOTTOM
SCALE 2.250
.700
.823
R.437
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 7 - Part A
Pro/E Drawing File
PULLEY_7_A
SIZE A
SCALE 1.250
SHEET 4 OF 5


For Educational Use Only
2
B
A
1
B.C. Ø.625
4 6-32 TAP
90° APART
.050
.2300±.0015
.197
.195
.032
.029
DETAIL TOP END
SCALE 3.000
DETAIL TOP
SCALE 2.000
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Pulley - 7 - Part A
Pro/E Drawing File
PULLEY_7_A
SIZE A
SCALE 1.250
SHEET 5 OF 5

11-16-00

2

B



ISOMETRIC VIEW

For Educational Use Only

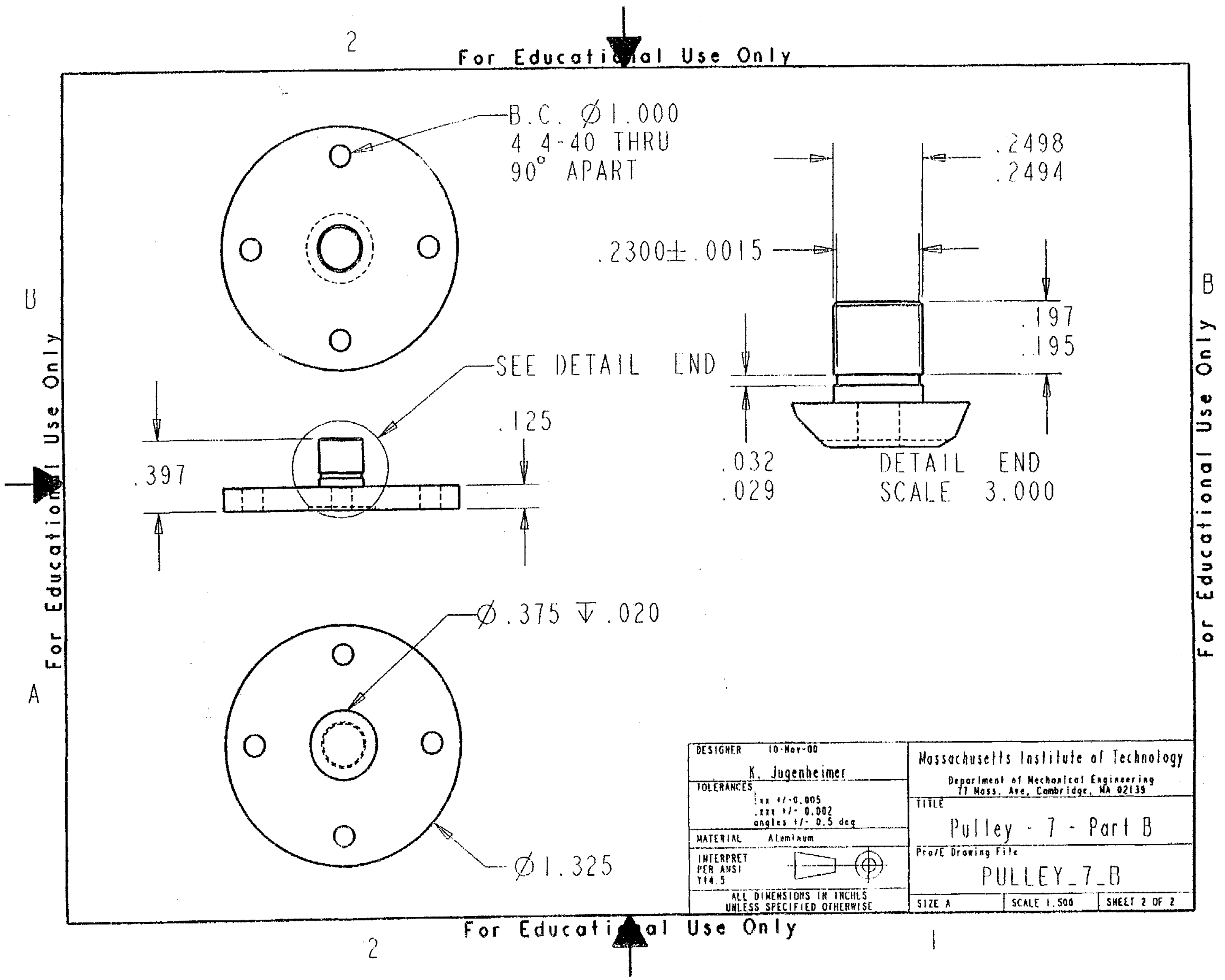
A

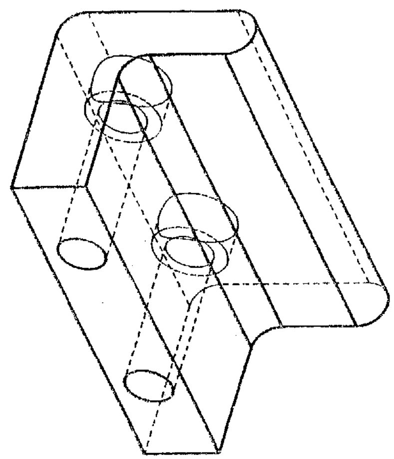
DESIGNER 10-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES xx +/- 0.005 xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley - 7 - Part B
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_7_B
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 2.000 / SHEET 1 OF 2

For Educational Use Only

2

1


For Educational Use Only
B.C. ∅1.000
4 4-40 THRU
90° APART
.2498
.2494
.2300±.0015
.197
.195
SEE DETAIL END
.125
.397
.032
.029
DETAIL END
SCALE 3.000
∅.375 ↧.020
∅1.325
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Pulley - 7 - Part B
Pro/E Drawing File
PULLEY_7_B
SIZE A
SCALE 1.500
SHEET 2 OF 2



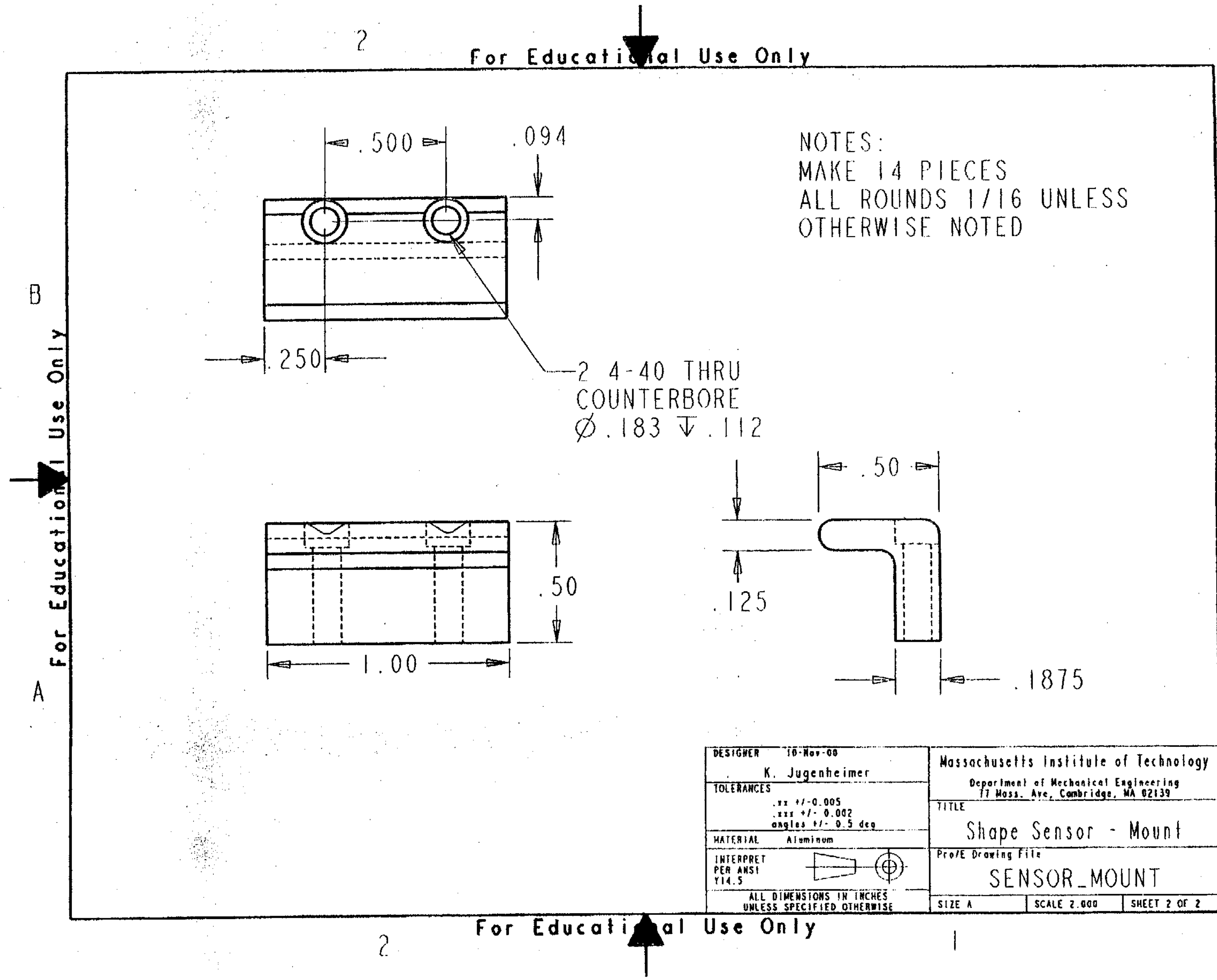
ISOMETRIC VIEW

DESIGNER 10-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Shape Sensor - Mount
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File SENSOR_MOUNT
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 3.000 | SHEET 1 OF 2

For Educational Use Only

For Educational Use Only

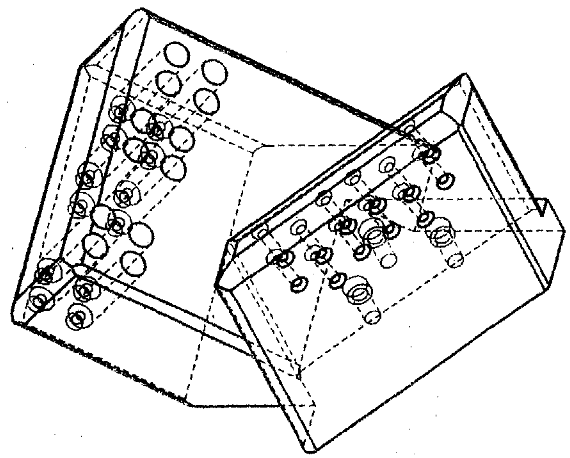
For Educational Use Only


For Educational Use Only
NOTES:
MAKE 14 PIECES
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
.500
.094
.250
2 4-40 THRU
COUNTERBORE
∅.183 ↧.112
.50
.125
.50
1.00
.1875
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Shape Sensor - Mount
Pro/E Drawing File
SENSOR_MOUNT
SIZE A
SCALE 2.000
SHEET 2 OF 2

11-14-00

2

B



ISOMETRIC VIEW

A

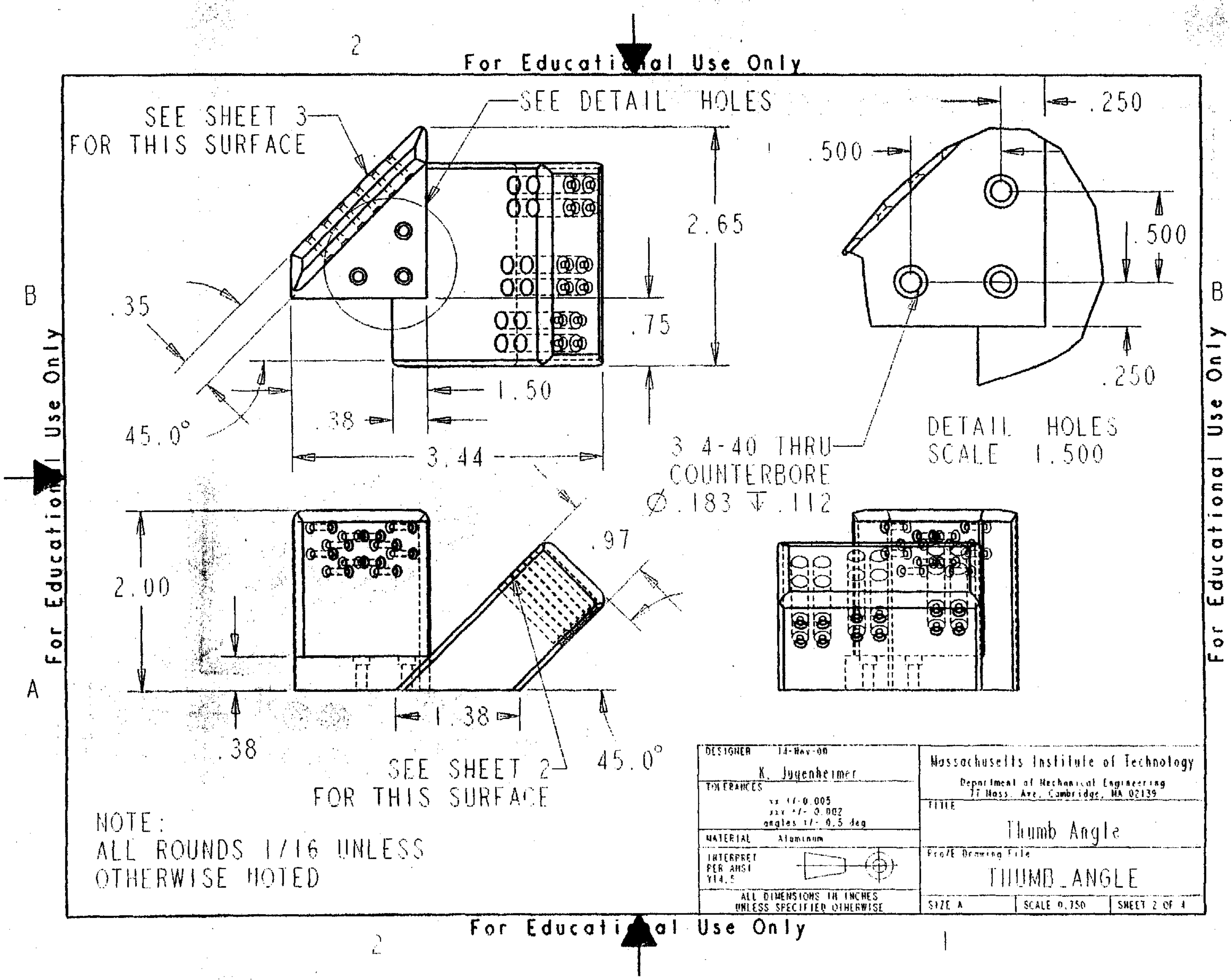
DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Angle
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_ANGLE
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.000 | SHEET 1 OF 4

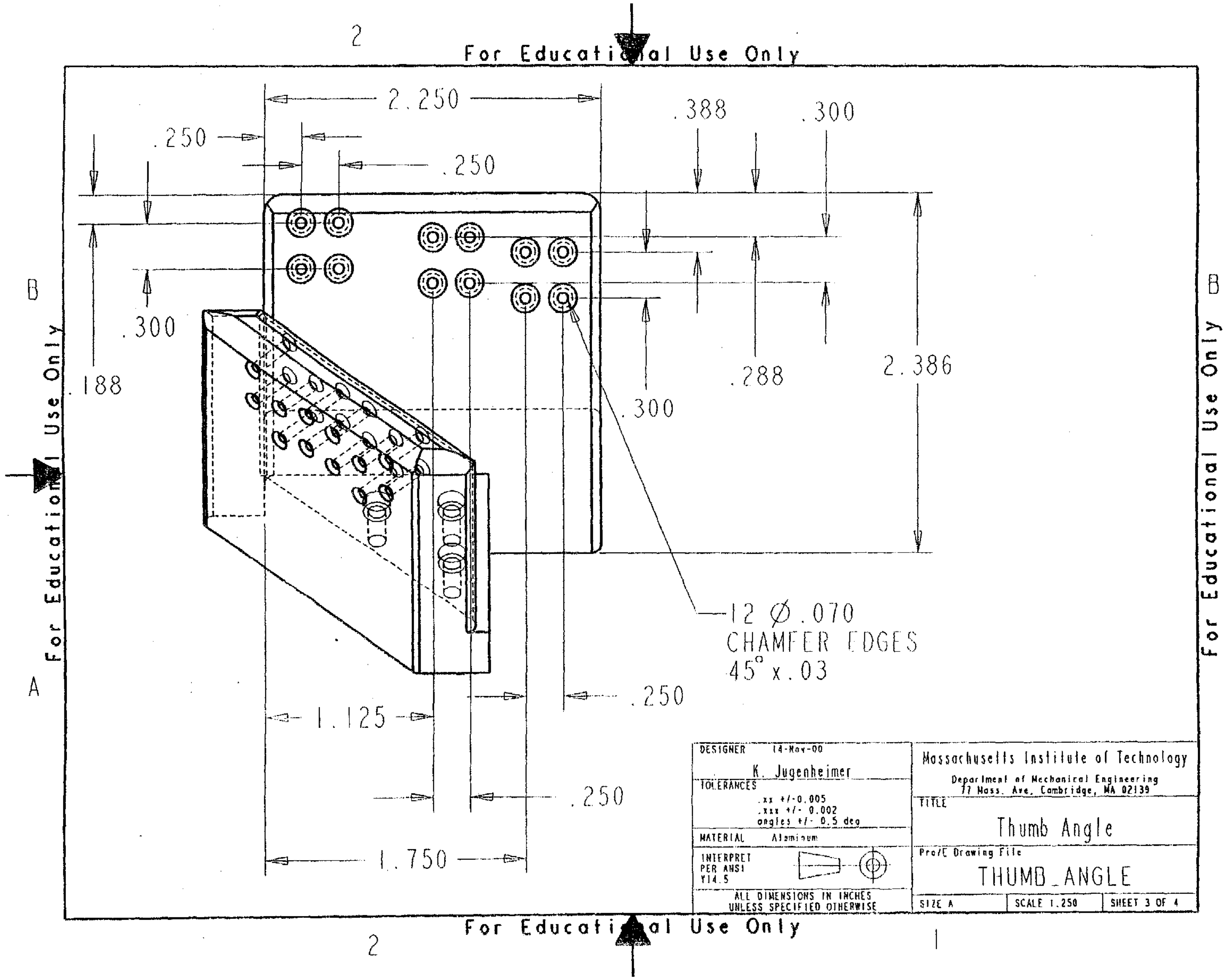
For Educational Use Only

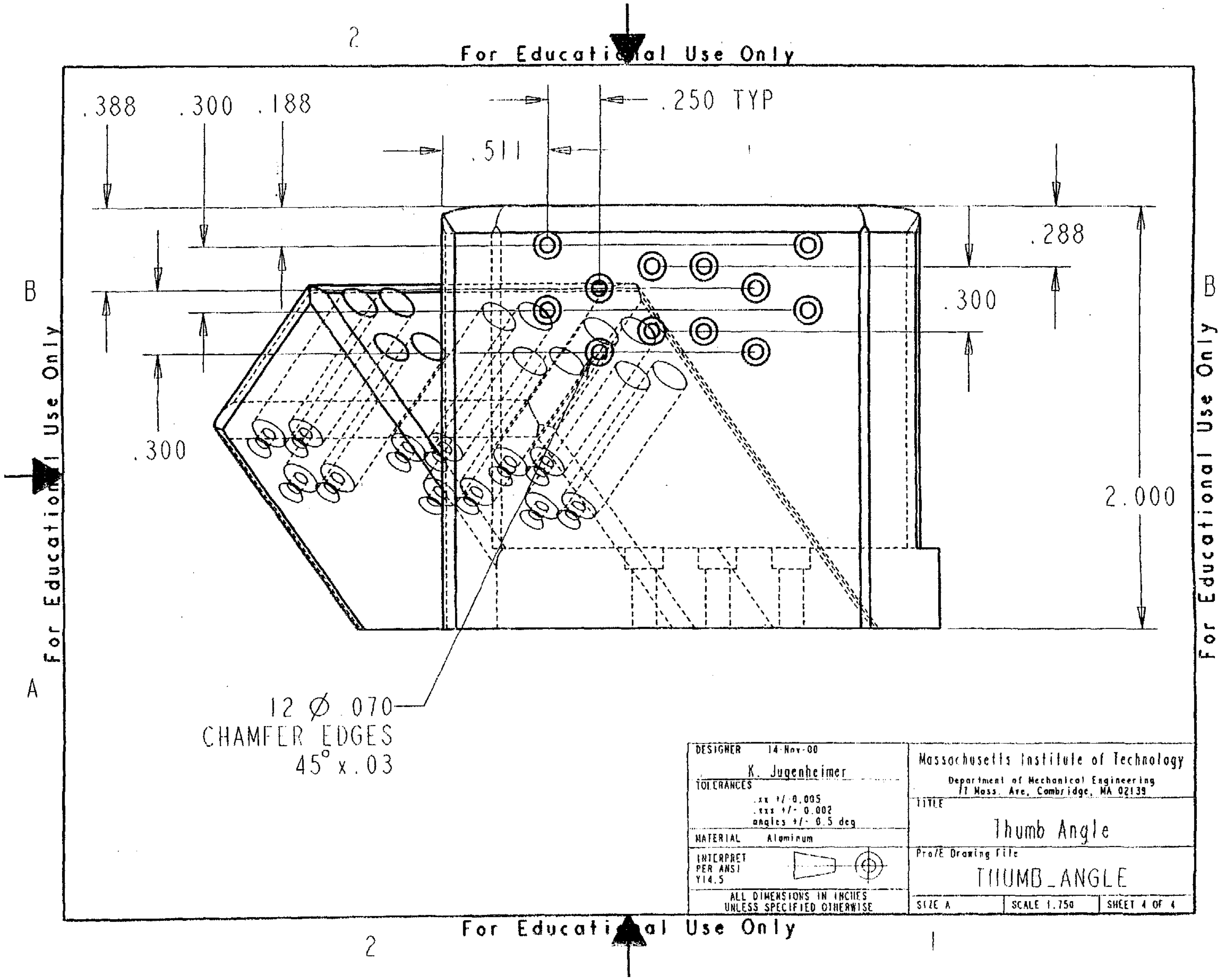
For Educational Use Only

For Educational Use Only

2 1


For Educational Use Only
SEE SHEET 3 FOR THIS SURFACE
SEE DETAIL HOLES
2.65
.35
.75
45.0°
1.50
.38
3.44
.250
.500
.500
.250
3 4-40 THRU COUNTERBORE ∅.183 ↧.112
DETAIL HOLES SCALE 1.500
2.00
.97
.38
1.38
45.0°
SEE SHEET 2 FOR THIS SURFACE
NOTE:
ALL ROUNDS 1/16 UNLESS OTHERWISE NOTED
DESIGNER 14-May-00
K. Jugenheimer
TOLERANCES
xx +/- 0.005
xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Thumb Angle
Pro/E Drawing File
THUMB_ANGLE
SIZE A
SCALE 0.750
SHEET 2 OF 4
A
B
1
2

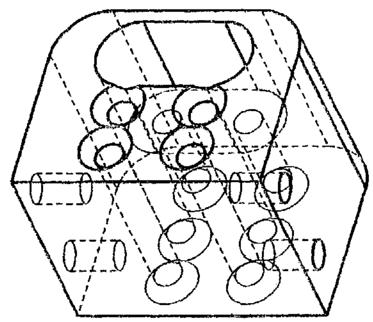

For Educational Use Only
2
2.250
.250
.250
.388
.300
B
.300
.188
.288
2.386
.300
12 ∅.070
CHAMFER EDGES
45° x .03
A
.250
1.125
.250
1.750
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Angle
Pro/E Drawing File
THUMB_ANGLE
SIZE A
SCALE 1.250
SHEET 3 OF 4
1


For Educational Use Only
.388
.300
.188
.511
.250 TYP
.288
.300
.300
2.000
B
B
A
2
2
1
12 Ø .070
CHAMFER EDGES
45° x .03
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Angle
Pro/E Drawing File
THUMB_ANGLE
SIZE A
SCALE 1.750
SHEET 4 OF 4

2

B

For Educational Use Only



ISOMETRIC VIEW

For Educational Use Only

B

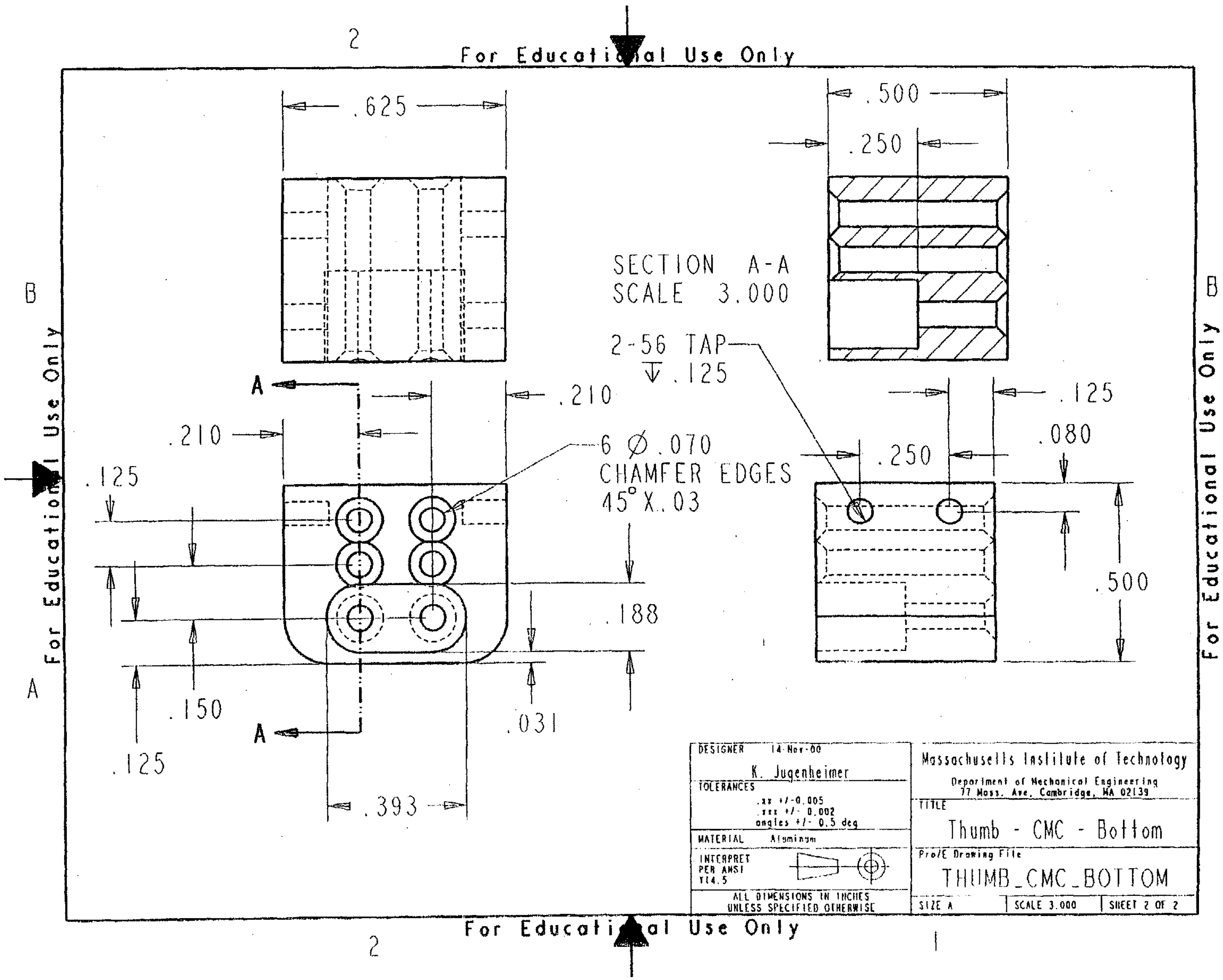
A

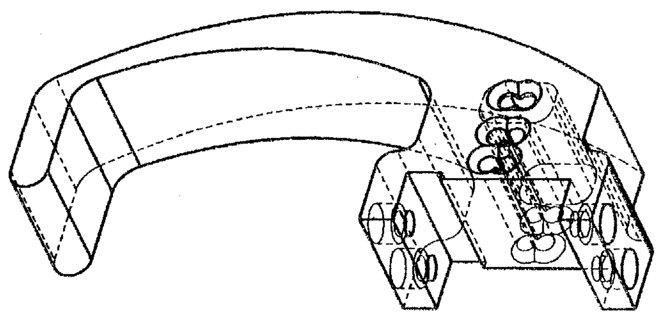
DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - CMC - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_CMC_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A	SCALE 3.000	SHEET 1 OF 2

For Educational Use Only

2

1

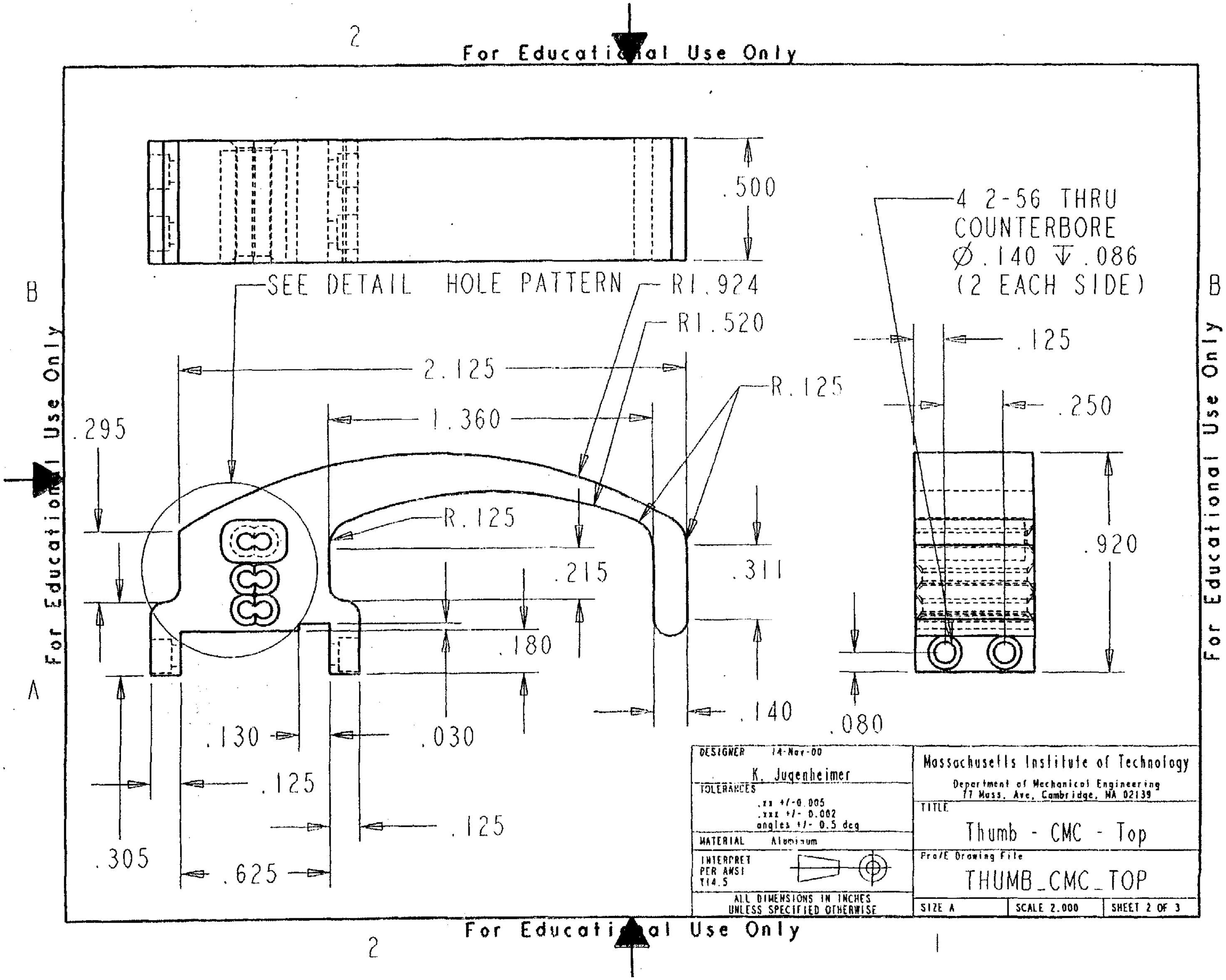

For Educational Use Only
SECTION A-A
SCALE 3.000
2-56 TAP
↧ .125
6 Ø .070
CHAMFER EDGES
45° X .03
.625
.500
.250
.210
.125
.080
.188
.150
.031
.393
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Thumb - CMC - Bottom
Pro/E Drawing File
THUMB_CMC_BOTTOM
SIZE A
SCALE 3.000
SHEET 2 OF 2

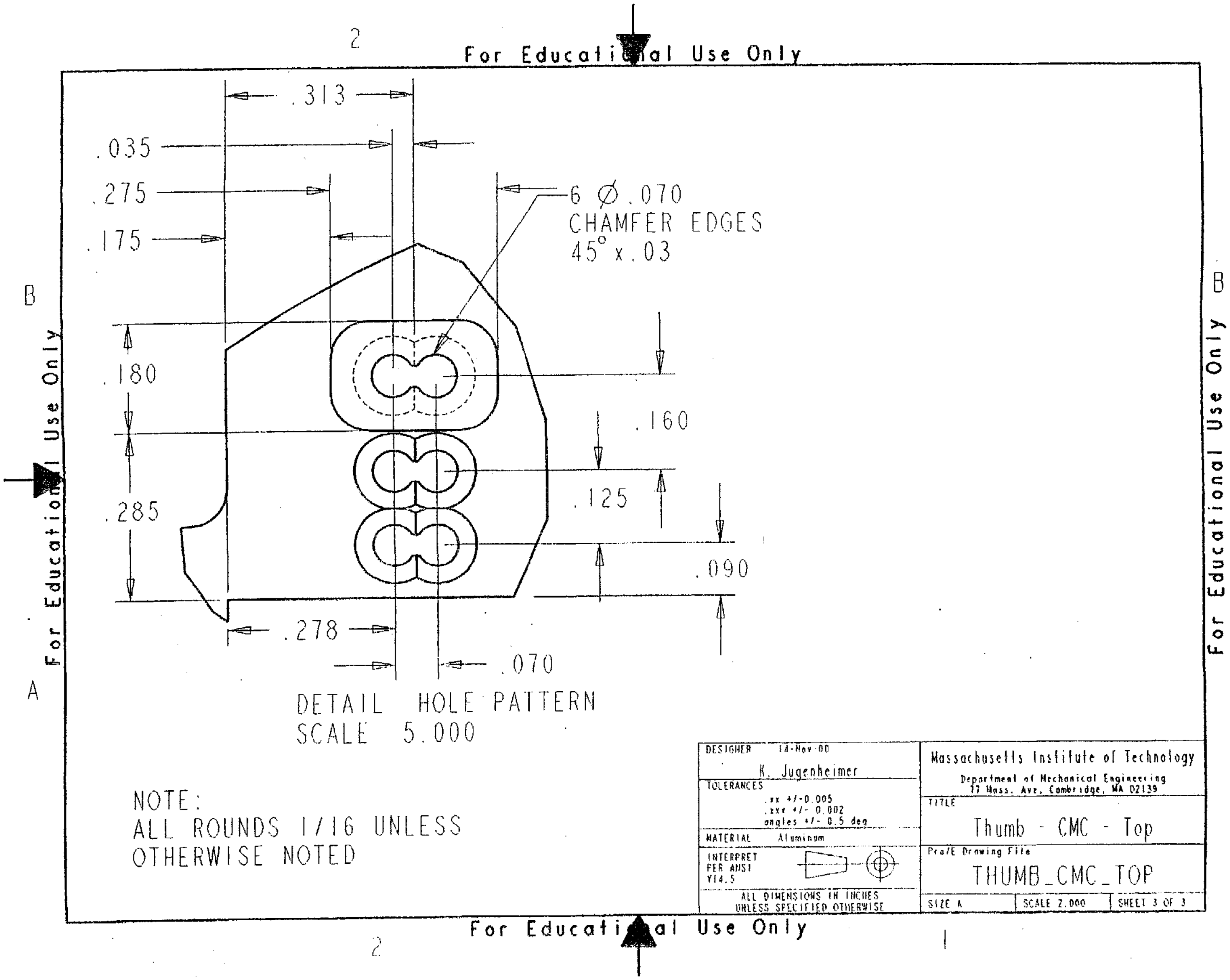


ISOMETRIC VIEW

DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - CMC - Top
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_CMC_TOP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 3

For Educational Use Only

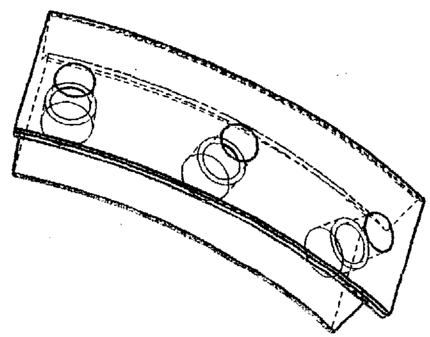

For Educational Use Only
.500
4 2-56 THRU
COUNTERBORE
Ø.140 ↧.086
(2 EACH SIDE)
SEE DETAIL HOLE PATTERN
R1.924
R1.520
2.125
1.360
R.125
R.125
.295
.215
.311
.180
.125
.250
.920
.140
.080
.130
.030
.125
.125
.305
.625
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Thumb - CMC - Top
Pro/E Drawing File
THUMB_CMC_TOP
SIZE A
SCALE 2.000
SHEET 2 OF 3


For Educational Use Only
.313
.035
.275
.175
6 Ø.070
CHAMFER EDGES
45° x.03
.180
.285
.160
.125
.090
.278
.070
DETAIL HOLE PATTERN
SCALE 5.000
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - CMC - Top
Pro/E Drawing File
THUMB_CMC_TOP
SIZE A
SCALE 2.000
SHEET 3 OF 3

2

B

For Educational Use Only



ISOMETRIC VIEW

A

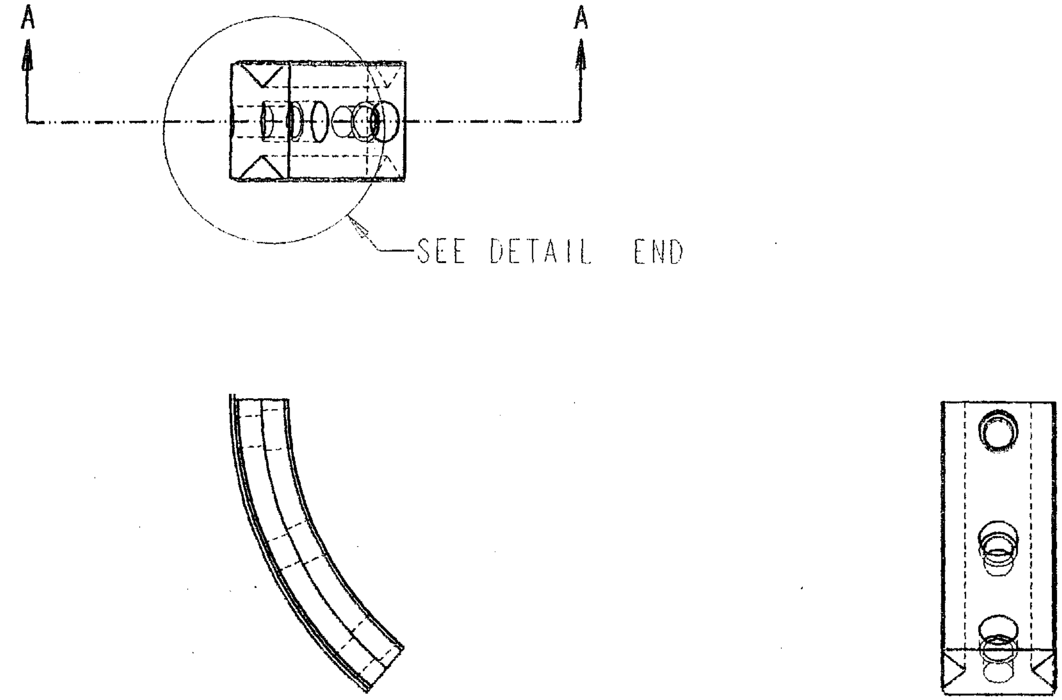
B

For Educational Use Only

DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005, .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb CMC Base - 1
MATERIAL Delrin	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_CMC_BASE_1
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 3

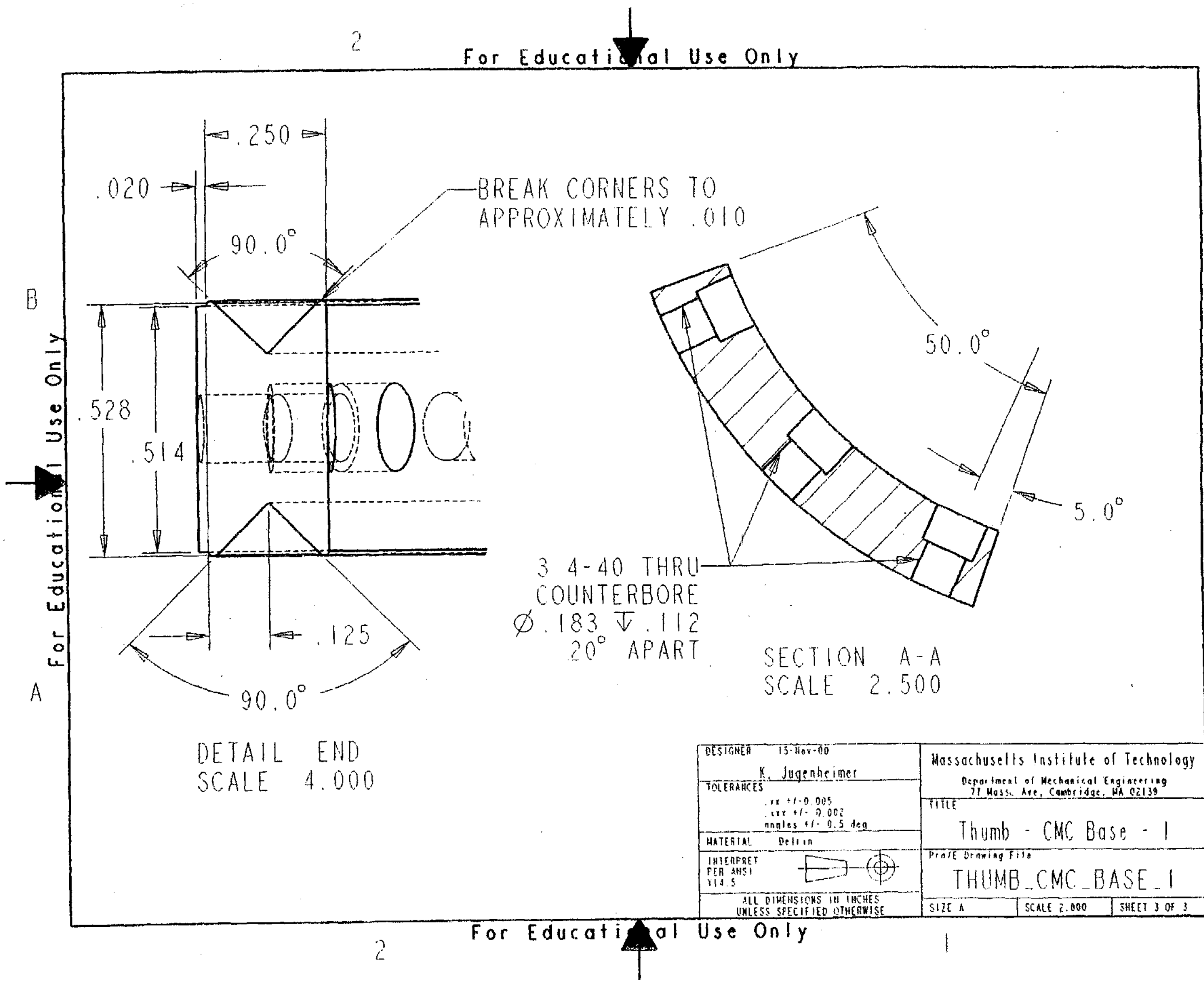
For Educational Use Only

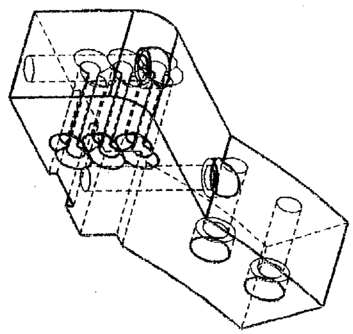
2 1



DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - CMC Base - 1
MATERIAL Delrin	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_CMC_BASE_1
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 1.500 / SHEET 2 OF 3

For Educational Use Only

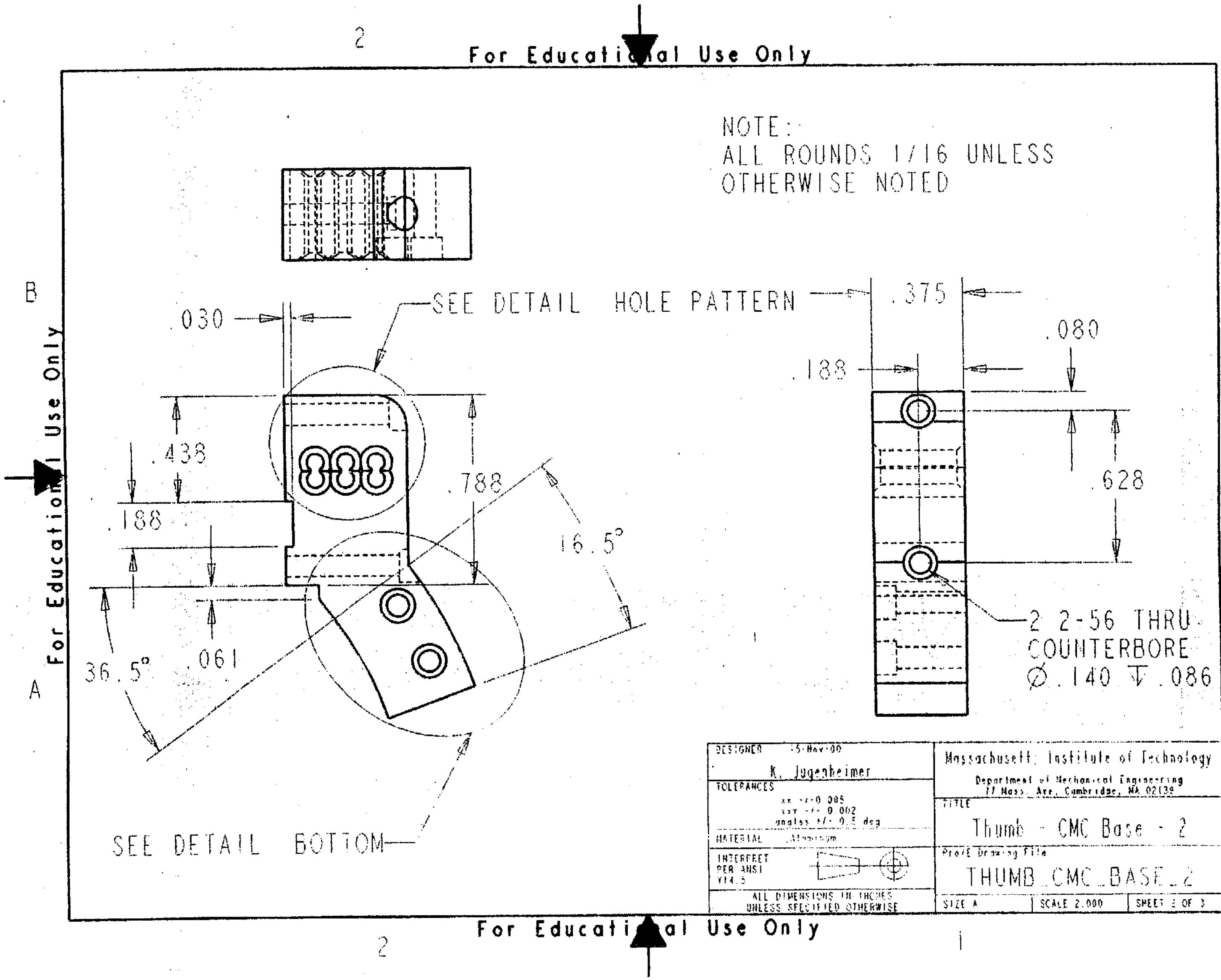

For Educational Use Only
.250
.020
BREAK CORNERS TO APPROXIMATELY .010
90.0°
.528
.514
.125
90.0°
DETAIL END
SCALE 4.000
50.0°
5.0°
3 4-40 THRU
COUNTERBORE
∅.183 ↧.112
20° APART
SECTION A-A
SCALE 2.500
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Delrin
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - CMC Base - 1
Pro/E Drawing File
THUMB_CMC_BASE_1
SIZE A
SCALE 2.000
SHEET 3 OF 3



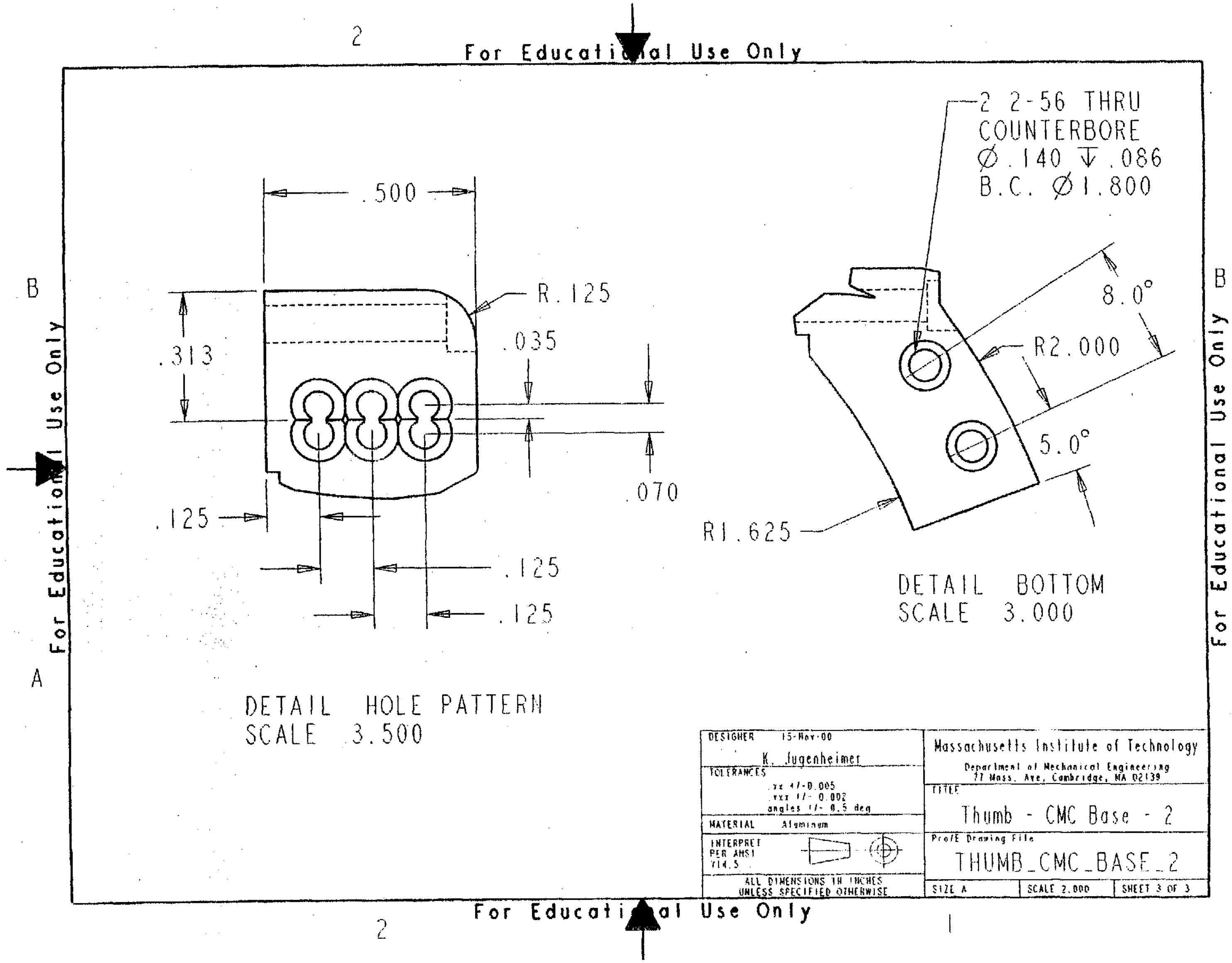
ISOMETRIC VIEW

DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - CMC Base - 2
MATERIAL Aluminum	Pro/E Drawing File THUMB_CMC_BASE_2
INTERPRET PER ANSI Y14.5	
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 2.000 / SHEET 1 OF 3

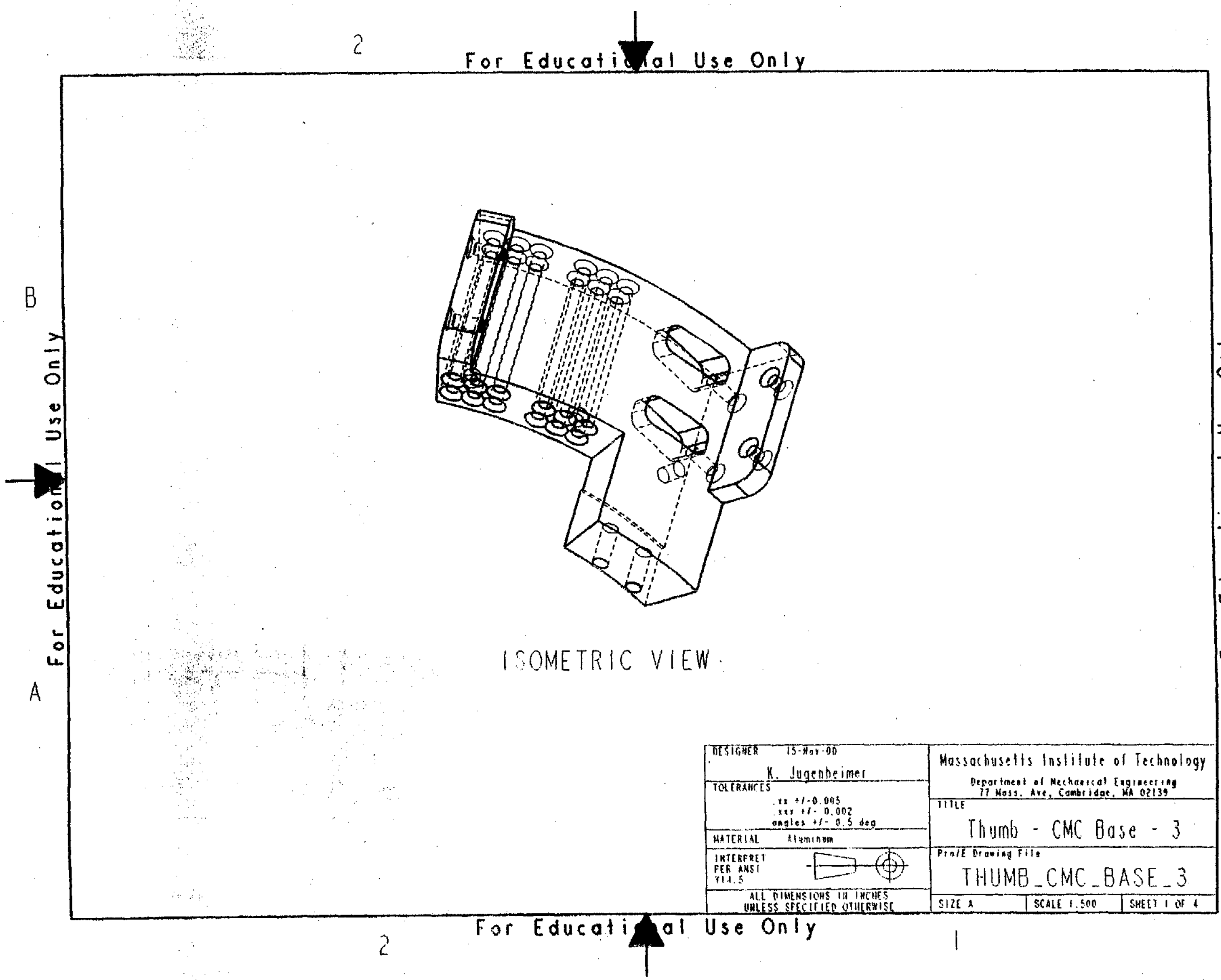
For Educational Use Only

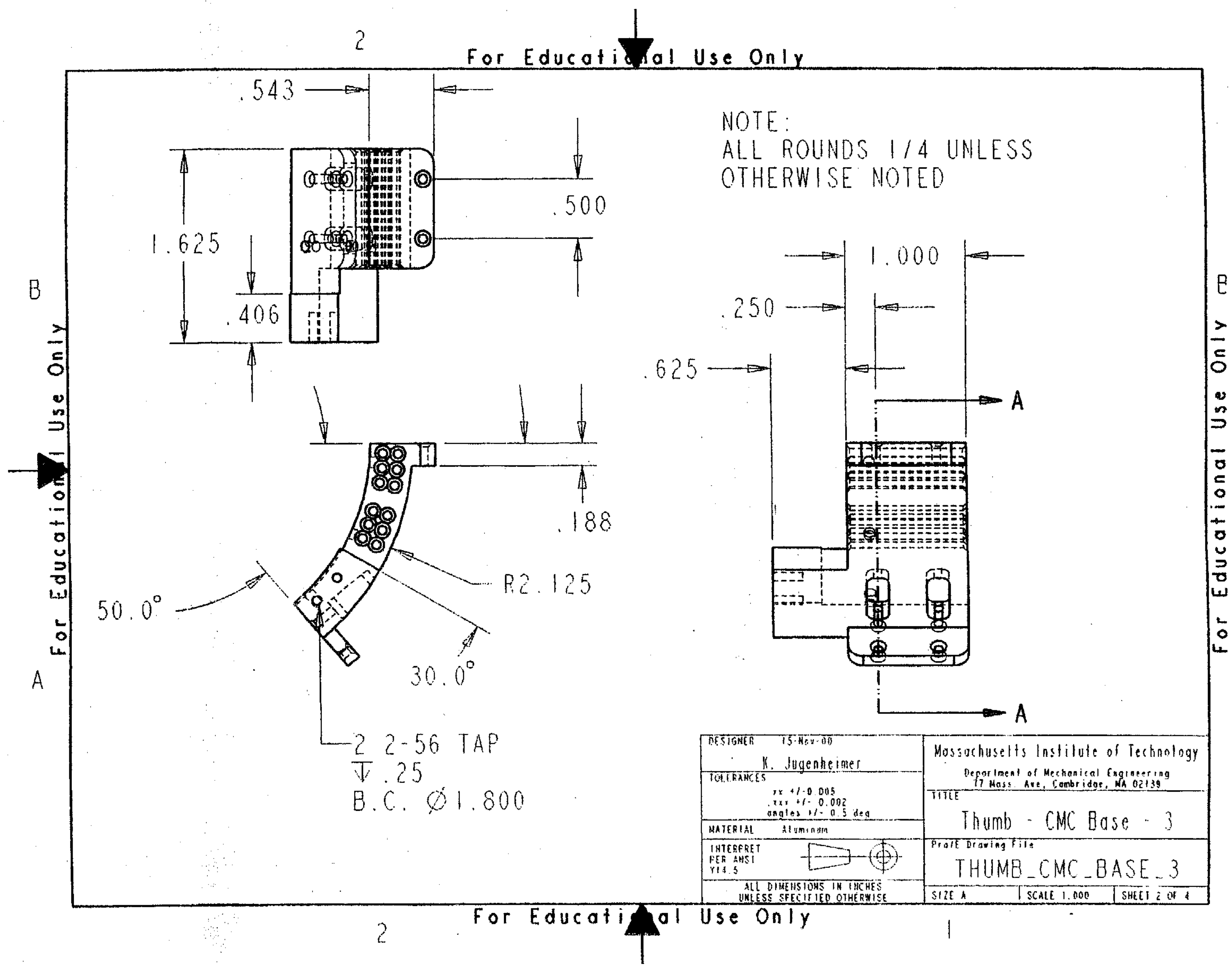


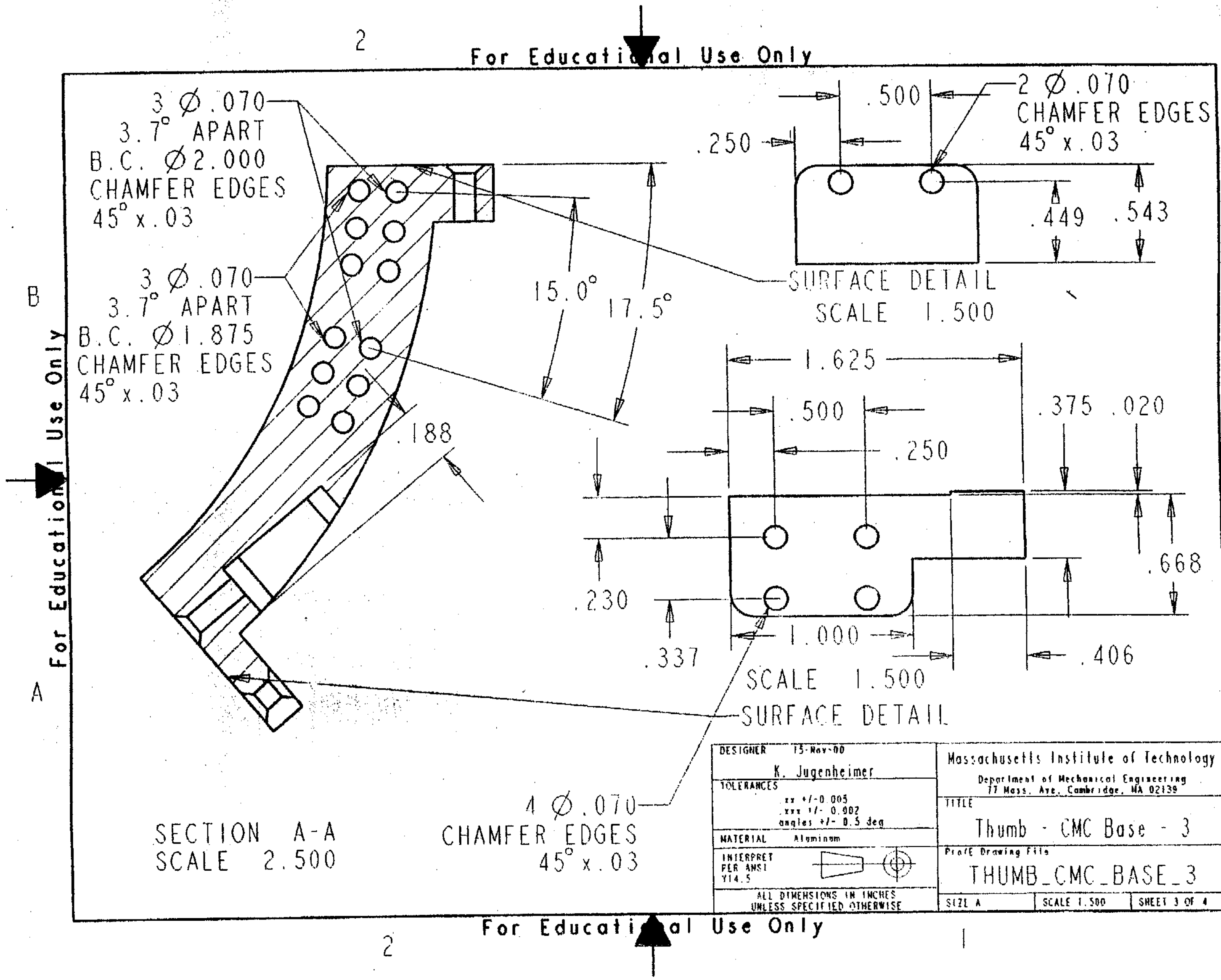
For Educational Use Only
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
SEE DETAIL HOLE PATTERN
.030
.438
.188
.061
36.5°
.788
16.5°
.375
.080
.188
.628
2 2-56 THRU
COUNTERBORE
∅.140 ↧.086
SEE DETAIL BOTTOM
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
xx +/- 0.005
xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Thumb - CMC Base - 2
ProE Drawing File
THUMB_CMC_BASE_2
SIZE A
SCALE 2.000
SHEET 2 OF 3

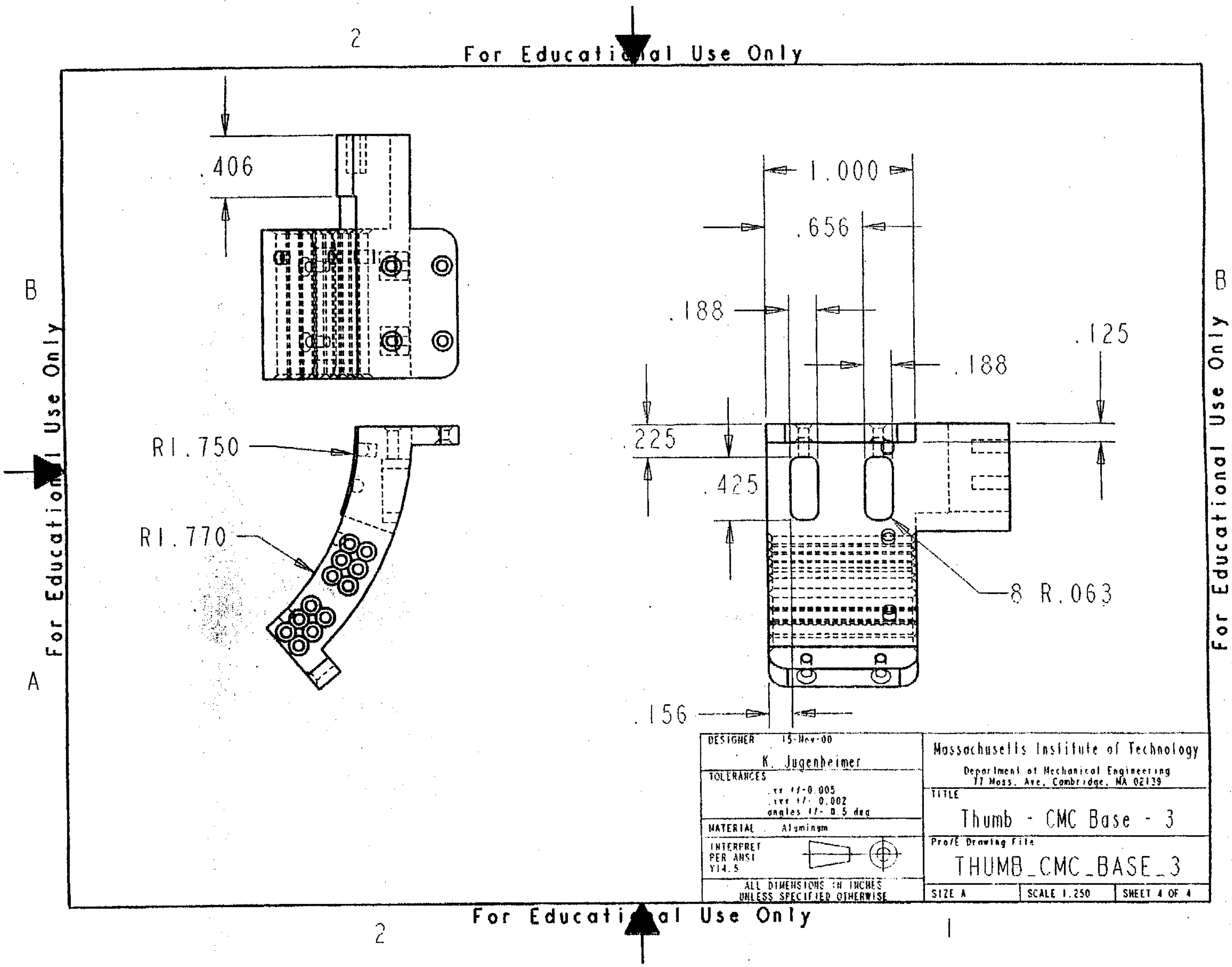


For Educational Use Only
2 2-56 THRU
COUNTERBORE
Ø.140 ↧ .086
B.C. Ø1.800
.500
R.125
.313
.035
.070
.125
.125
.125
8.0°
R2.000
5.0°
R1.625
DETAIL BOTTOM
SCALE 3.000
DETAIL HOLE PATTERN
SCALE 3.500
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - CMC Base - 2
Pro/E Drawing File
THUMB_CMC_BASE_2
SIZE A
SCALE 2.000
SHEET 3 OF 3


For Educational Use Only
ISOMETRIC VIEW
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - CMC Base - 3
Pro/E Drawing File
THUMB_CMC_BASE_3
SIZE A
SCALE 1.500
SHEET 1 OF 4


For Educational Use Only
.543
NOTE:
ALL ROUNDS 1/4 UNLESS
OTHERWISE NOTED
1.625
.500
.406
1.000
.250
.625
A
.188
R2.125
50.0°
30.0°
2 2-56 TAP
↧ .25
B.C. Ø1.800
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - CMC Base - 3
Pro/E Drawing File
THUMB_CMC_BASE_3
SIZE A
SCALE 1.000
SHEET 2 OF 4

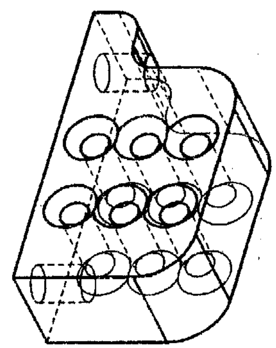

For Educational Use Only
3 Ø.070
3.7° APART
B.C. Ø2.000
CHAMFER EDGES
45° x.03
3 Ø.070
3.7° APART
B.C. Ø1.875
CHAMFER EDGES
45° x.03
15.0°
17.5°
.188
SURFACE DETAIL
SCALE 1.500
.500
.250
2 Ø.070
CHAMFER EDGES
45° x.03
.449
.543
1.625
.500
.250
.375
.020
.668
.230
.337
1.000
.406
SCALE 1.500
SURFACE DETAIL
4 Ø.070
CHAMFER EDGES
45° x.03
SECTION A-A
SCALE 2.500
DESIGNER 13-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave., Cambridge, MA 02139
TITLE
Thumb - CMC Base - 3
ProE Drawing File
THUMB_CMC_BASE_3
SIZE A
SCALE 1.500
SHEET 3 OF 4
A
B
2
1


For Educational Use Only
.406
R1.750
R1.770
1.000
.656
.188
.188
.125
.225
.425
8 R.063
.156
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - CMC Base - 3
Pro/E Drawing File
THUMB_CMC_BASE_3
SIZE A
SCALE 1.250
SHEET 4 OF 4

2

B

For Educational Use Only



ISOMETRIC VIEW

B

For Educational Use Only

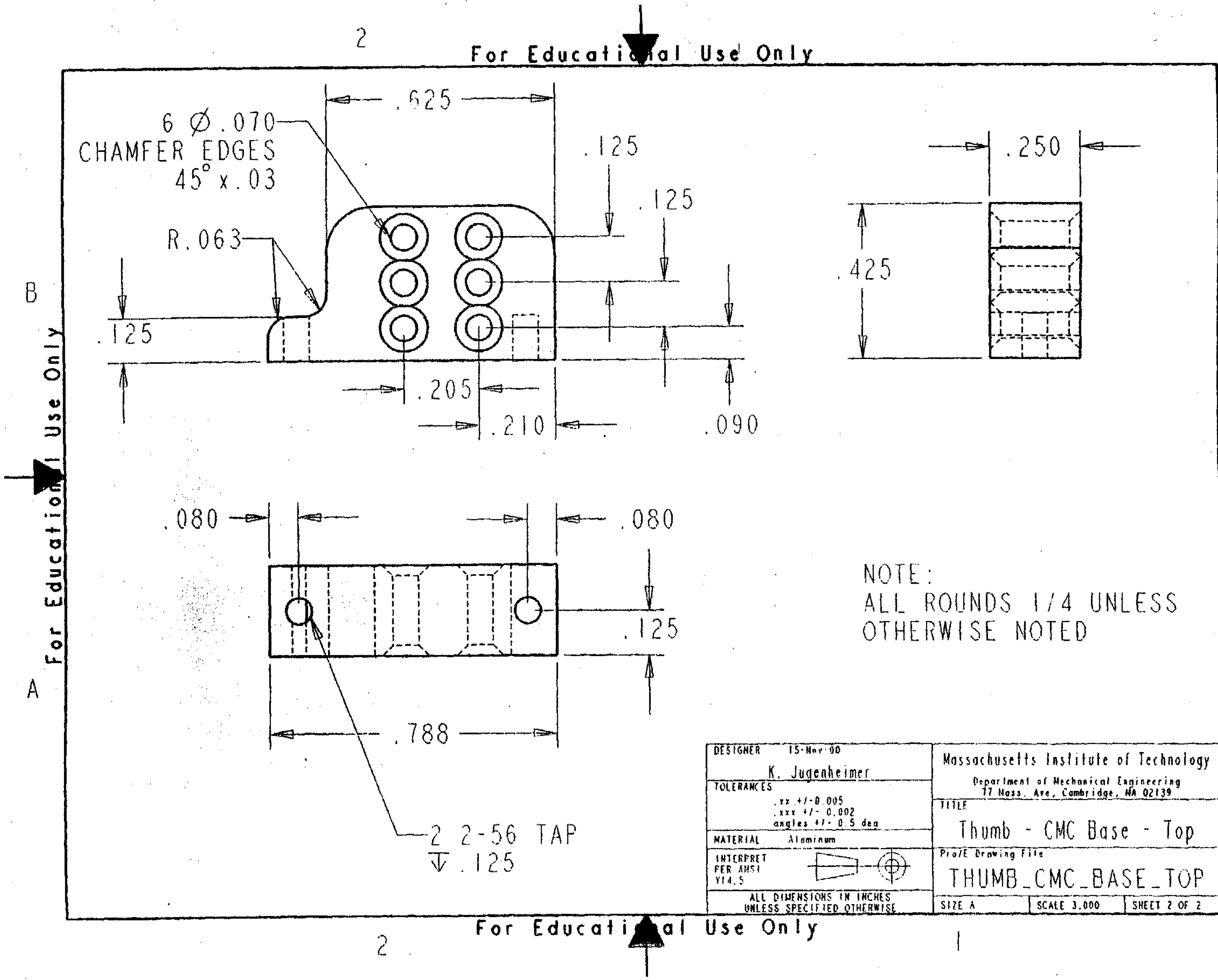
A

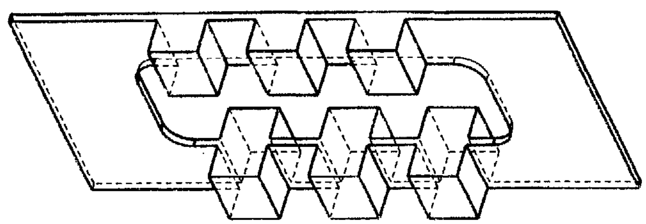
DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - CMC Base - Top
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_CMC_BASE_TOP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 3.000 / SHEET 1 OF 2

For Educational Use Only

2

1

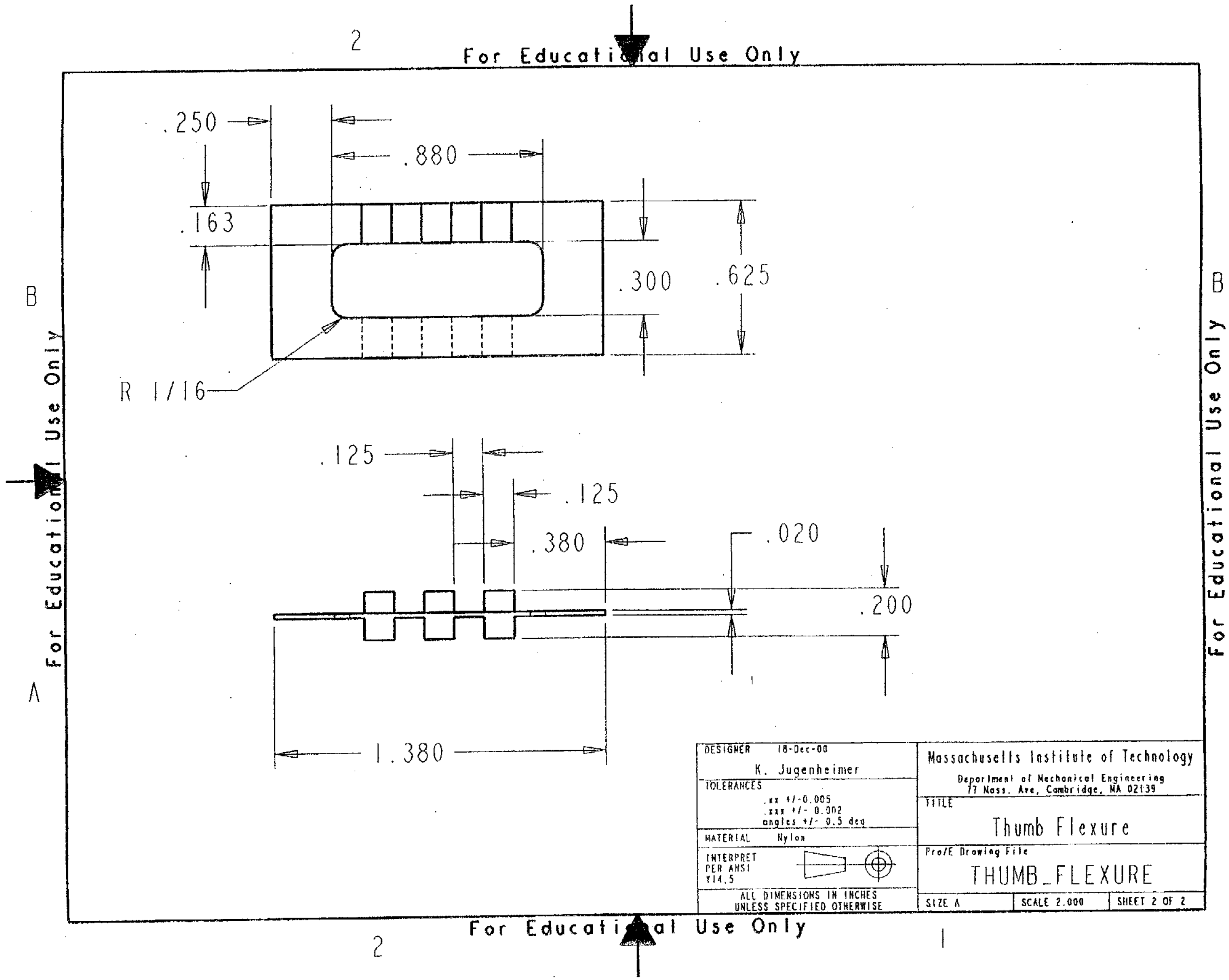

For Educational Use Only
6 Ø.070
CHAMFER EDGES
45° x .03
R.063
.625
.125
.125
.125
.205
.210
.090
.250
.425
.080
.080
.125
.788
2 2-56 TAP
↧ .125
NOTE:
ALL ROUNDS 1/4 UNLESS
OTHERWISE NOTED
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - CMC Base - Top
Pro/E Drawing File
THUMB_CMC_BASE_TOP
SIZE A
SCALE 3.000
SHEET 2 OF 2



ISOMETRIC VIEW

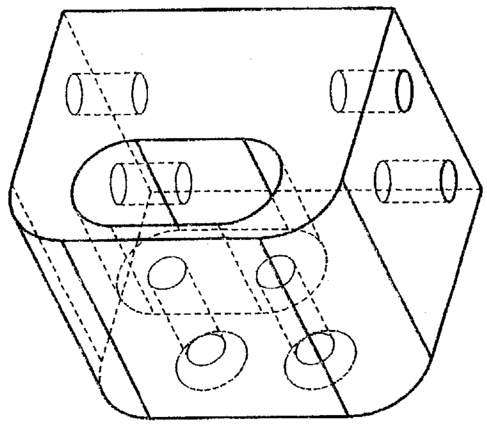
DESIGNER 10-Jan-01 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Flexure
MATERIAL Nylon	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_FLEXURE
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 3.000 / SHEET 1 OF 2

For Educational Use Only


For Educational Use Only
.250
.880
.163
.300
.625
R 1/16
.125
.125
.380
.020
.200
1.380
DESIGNER 18-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Nylon
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Flexure
Pro/E Drawing File
THUMB_FLEXURE
SIZE A
SCALE 2.000
SHEET 2 OF 2

2

B



ISOMETRIC VIEW

A

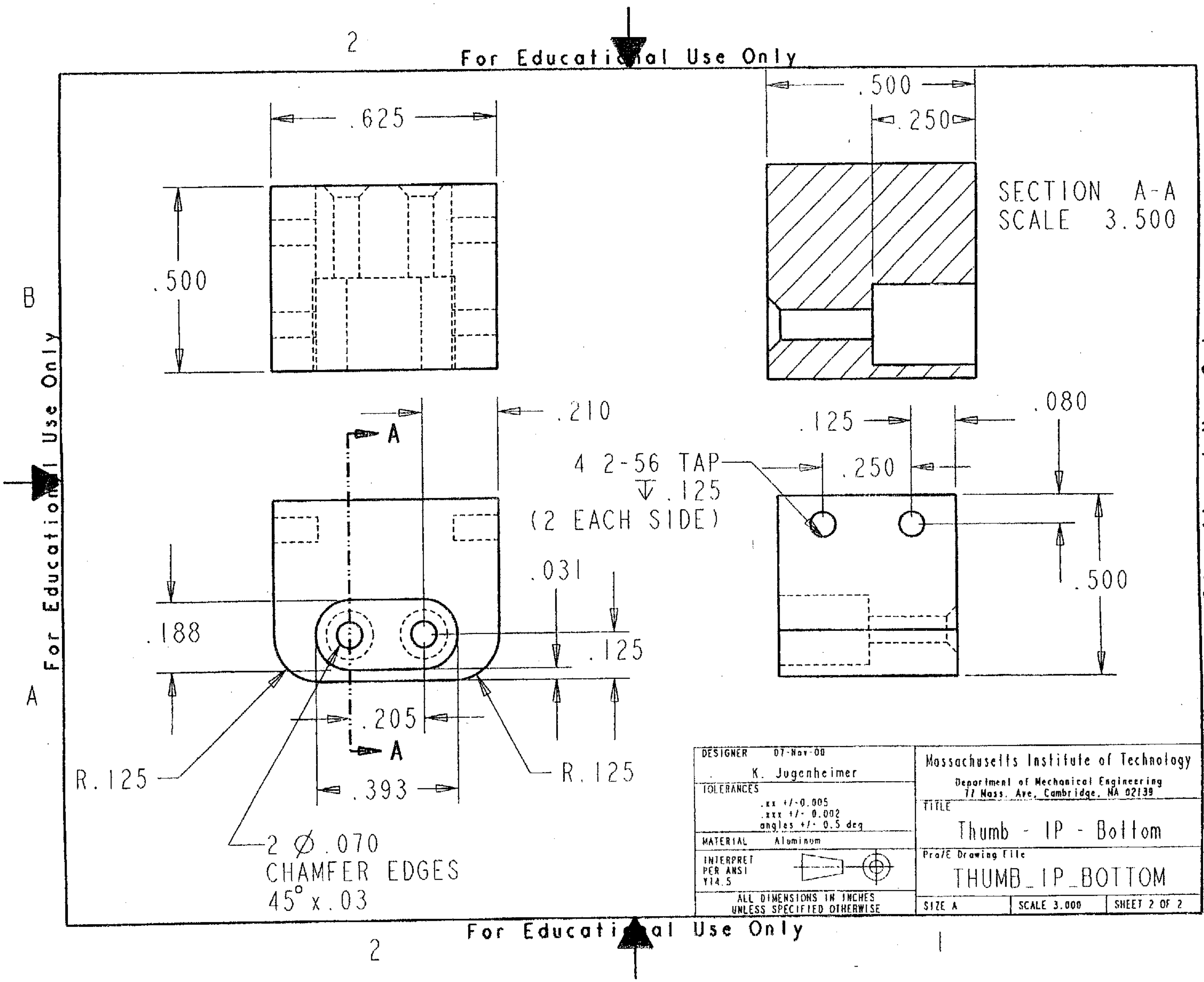
DESIGNER 07 Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - IP - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_IP_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 4.000 | SHEET 1 OF 2

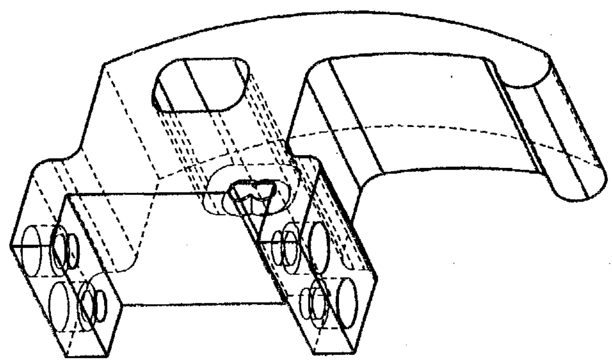
For Educational Use Only

For Educational Use Only

For Educational Use Only

2 1


For Educational Use Only
.625
.500
.500
.250
SECTION A-A
SCALE 3.500
.210
A
A
.125
.080
4 2-56 TAP
↧ .125
(2 EACH SIDE)
.250
.500
.031
.188
.125
.205
R.125
R.125
.393
2 Ø .070
CHAMFER EDGES
45° x .03
DESIGNER 07-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - IP - Bottom
Pro/E Drawing File
THUMB_IP_BOTTOM
SIZE A
SCALE 3.000
SHEET 2 OF 2



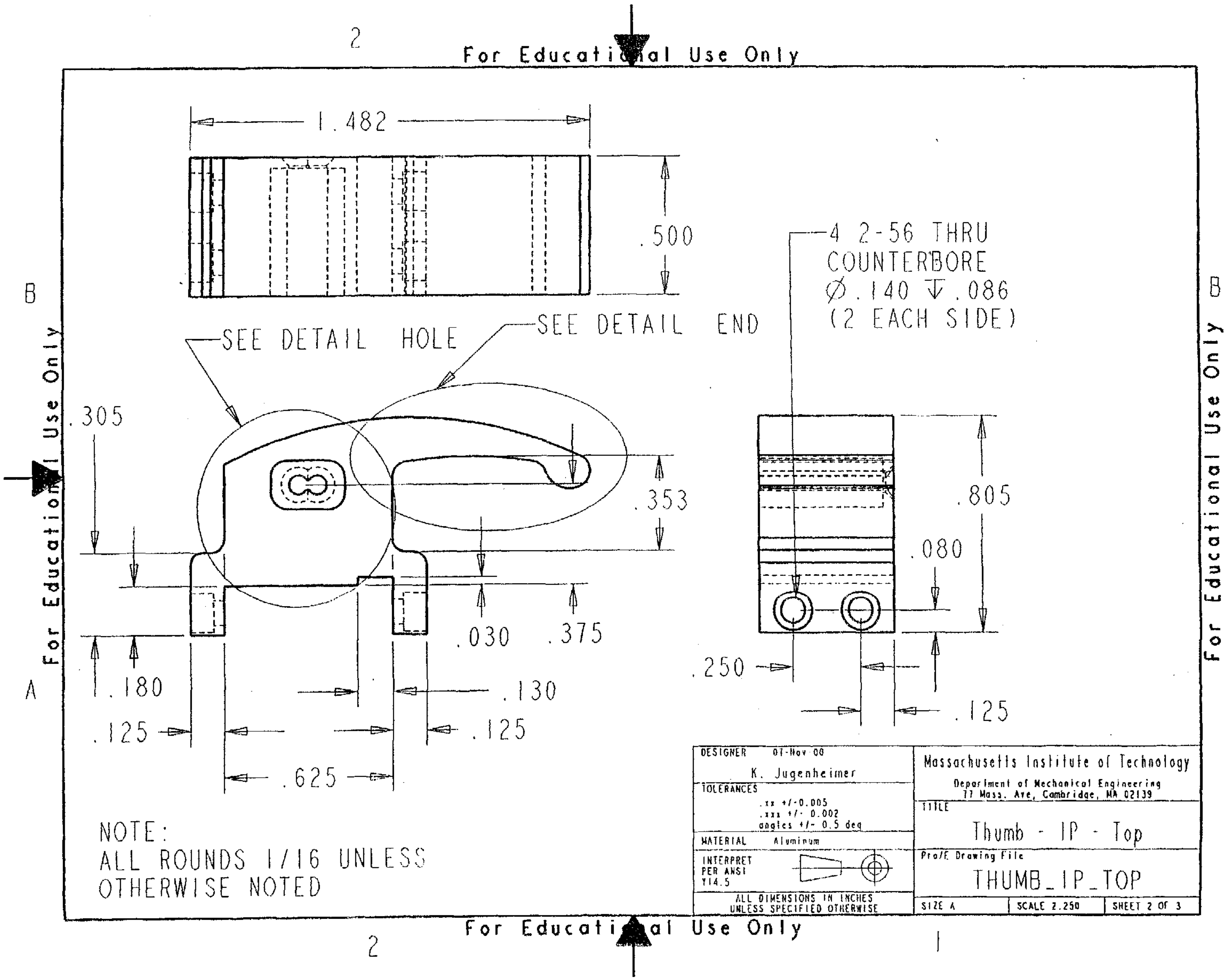
ISOMETRIC VIEW

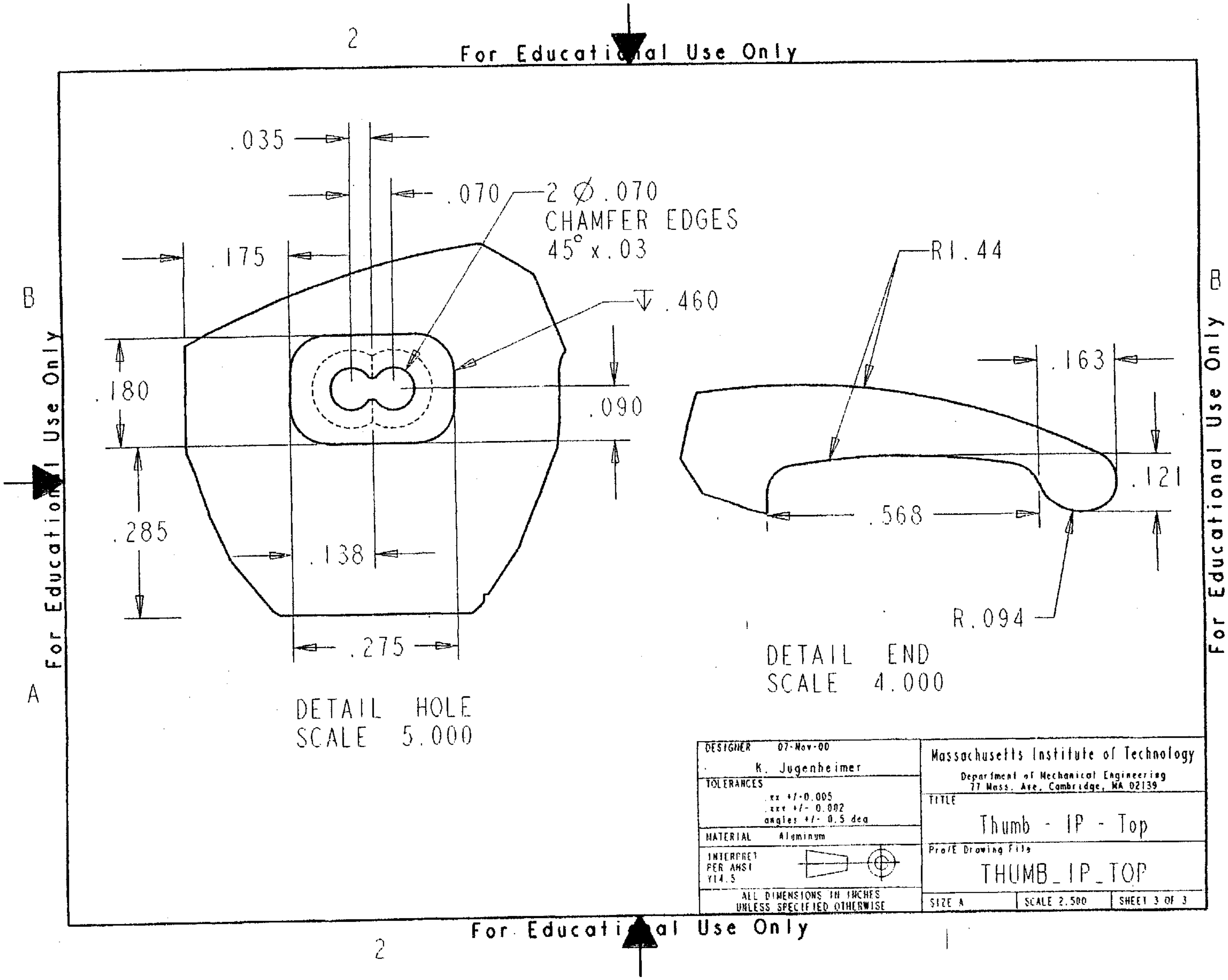
DESIGNER 07-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - IP - Top
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_IP_TOP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.500 | SHEET 1 OF 3

For Educational Use Only

For Educational Use Only

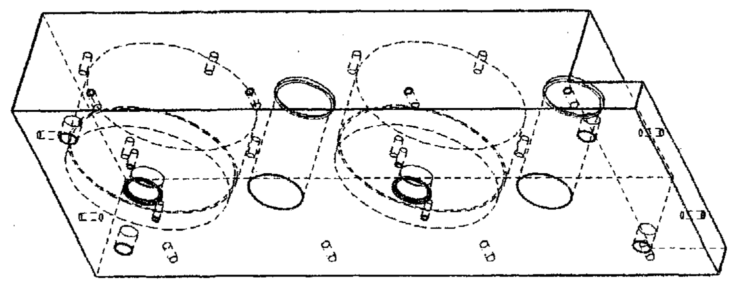
For Educational Use Only


For Educational Use Only
2
B
A
1.482
.500
.305
.353
.805
.080
.030
.375
.180
.130
.125
.625
.250
4 2-56 THRU
COUNTERBORE
∅.140 ↧.086
(2 EACH SIDE)
SEE DETAIL HOLE
SEE DETAIL END
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 07-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - IP - Top
Pro/E Drawing File
THUMB_IP_TOP
SIZE A
SCALE 2.250
SHEET 2 OF 3
1


For Educational Use Only
.035
.070
2 ∅.070
CHAMFER EDGES
45° x.03
.175
↧.460
.180
.090
.285
.138
.275
DETAIL HOLE
SCALE 5.000
R1.44
.163
.121
.568
R.094
DETAIL END
SCALE 4.000
DESIGNER 07-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - IP - Top
Pro/E Drawing File
THUMB_IP_TOP
SIZE A
SCALE 2.500
SHEET 3 OF 3

11-11-00

For Educational Use Only



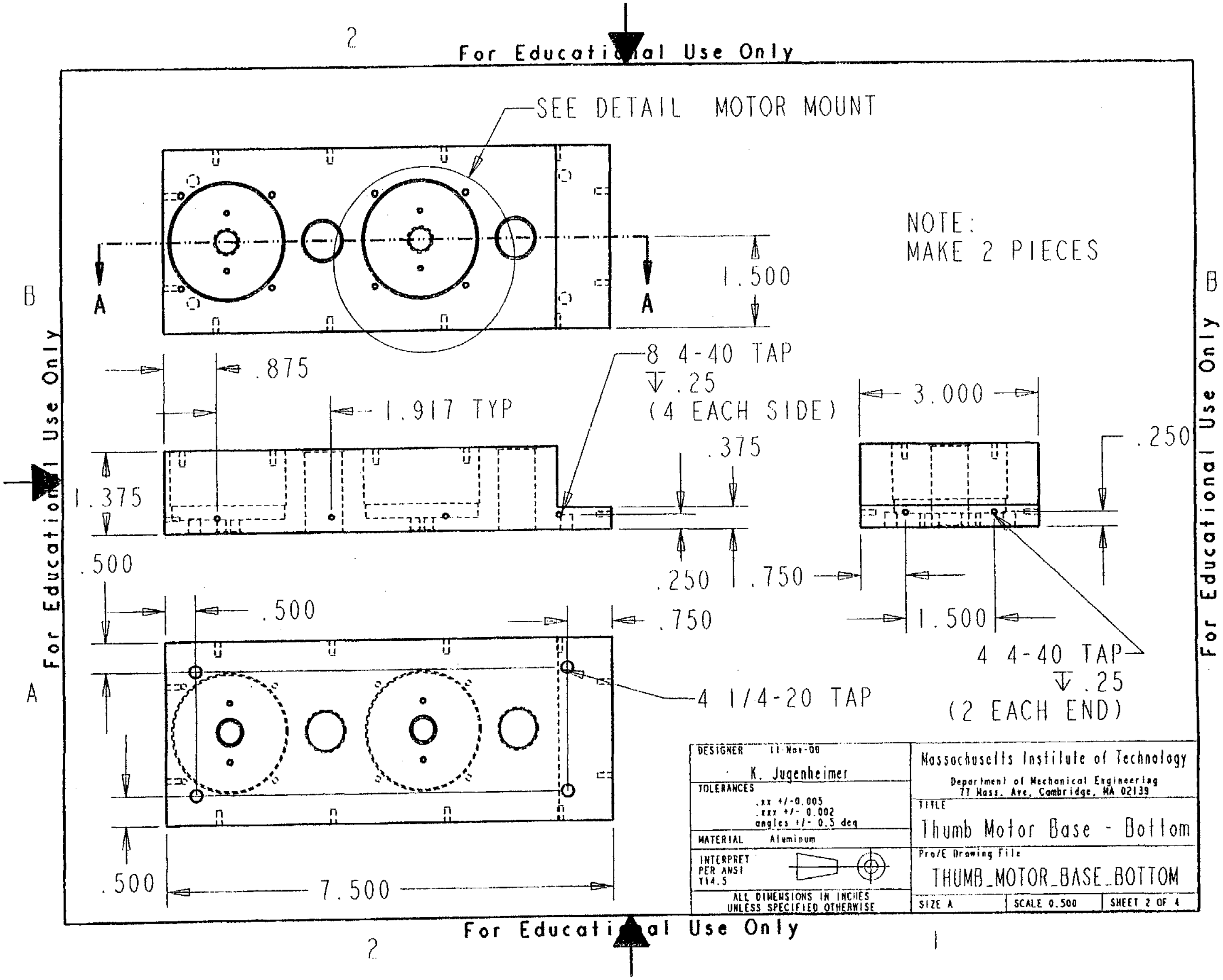
ISOMETRIC VIEW

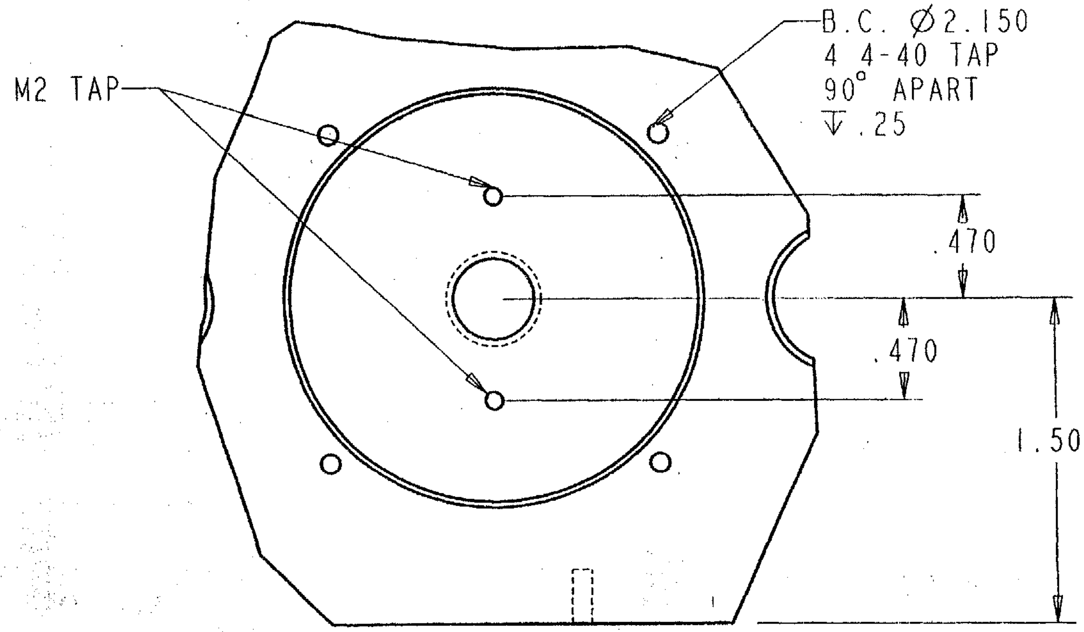
DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Motor Base - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_MOTOR_BASE_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.625 | SHEET 1 OF 4

For Educational Use Only

For Educational Use Only

For Educational Use Only

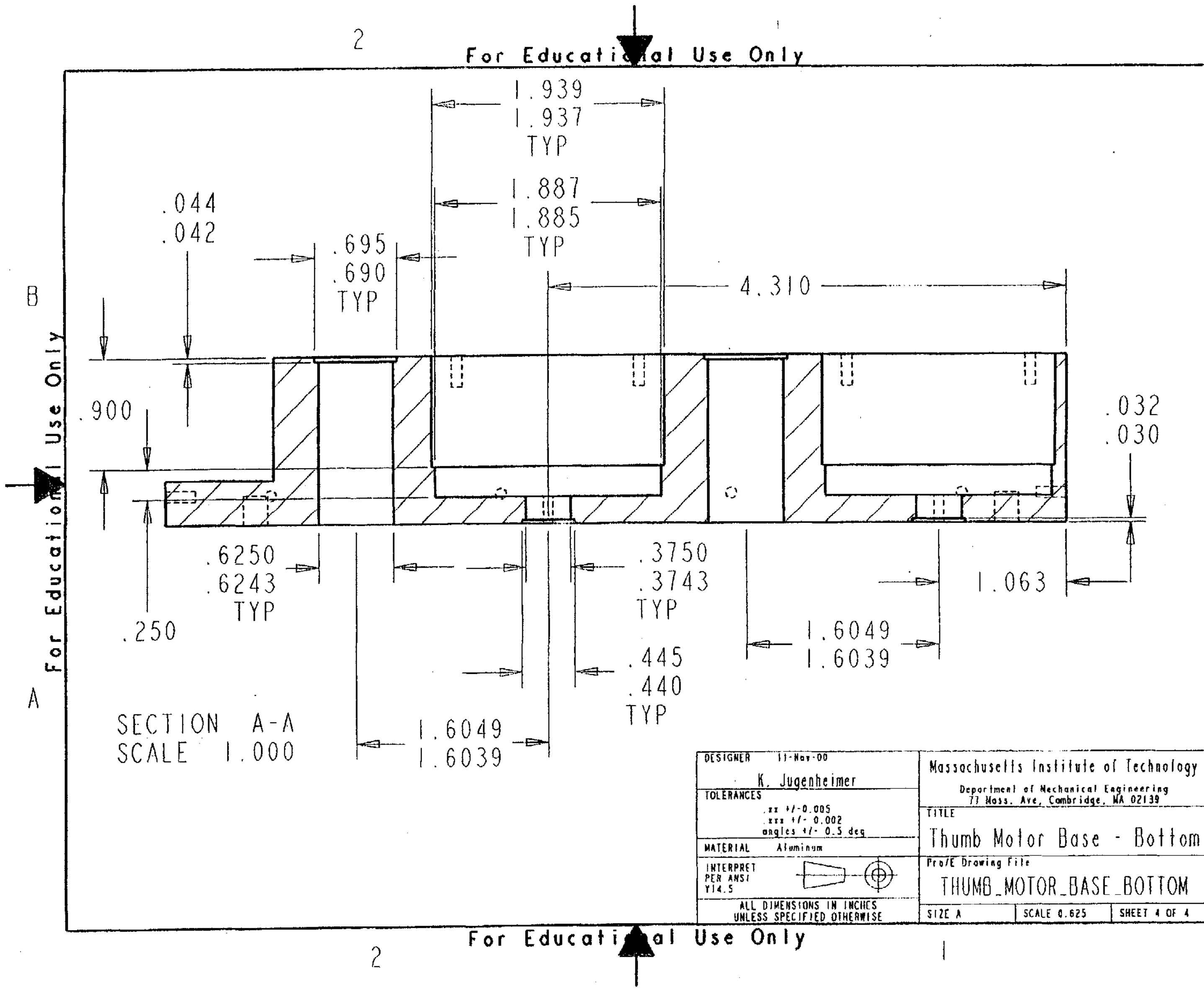

For Educational Use Only
SEE DETAIL MOTOR MOUNT
NOTE:
MAKE 2 PIECES
A
A
1.500
.875
1.917 TYP
8 4-40 TAP
⊽ .25
(4 EACH SIDE)
.375
1.375
.250
.750
3.000
.250
1.500
.500
.500
.750
4 1/4-20 TAP
4 4-40 TAP
⊽ .25
(2 EACH END)
.500
7.500
B
B
A
2
2
1
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - Bottom
Pro/E Drawing File
THUMB_MOTOR_BASE_BOTTOM
SIZE A
SCALE 0.500
SHEET 2 OF 4

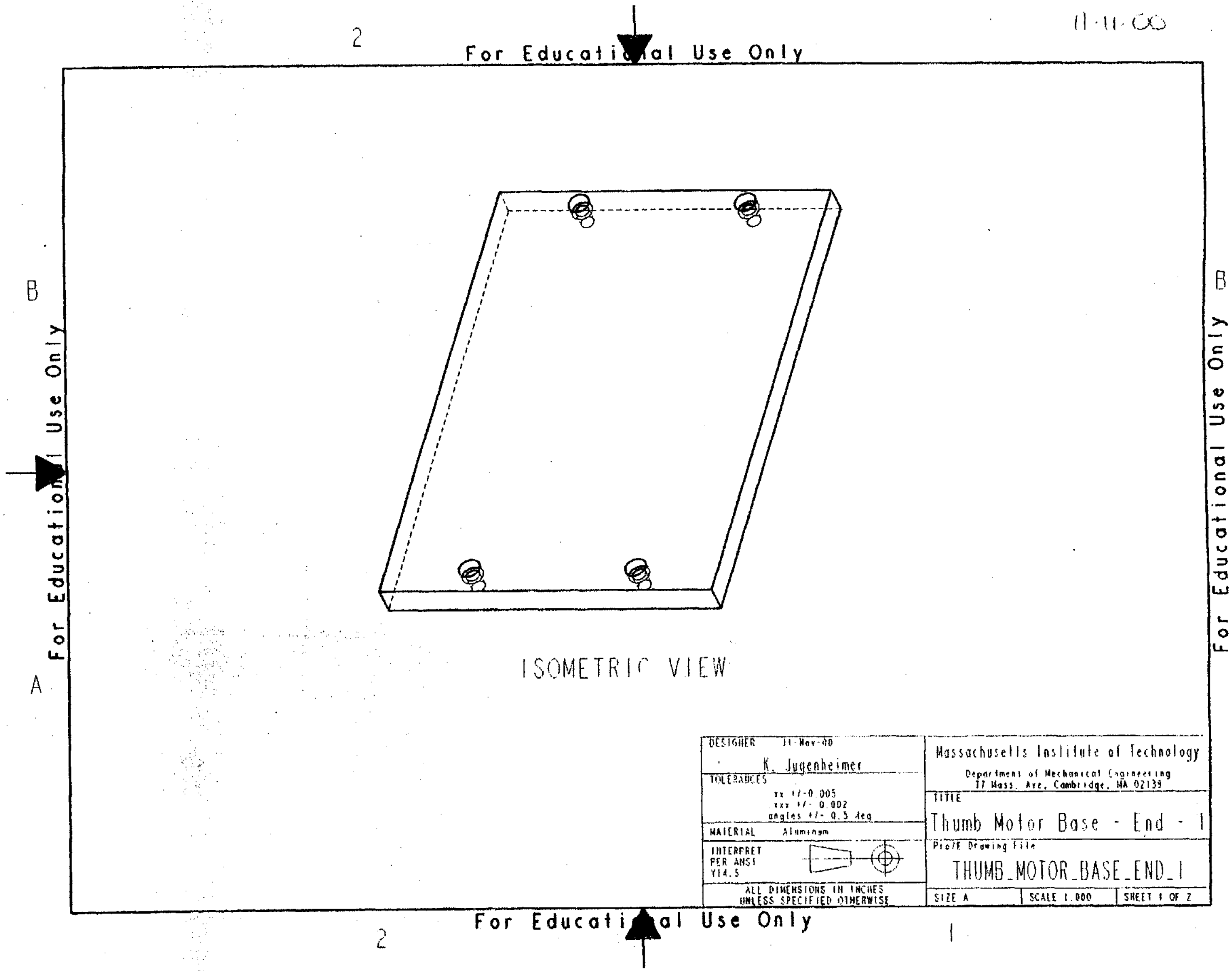


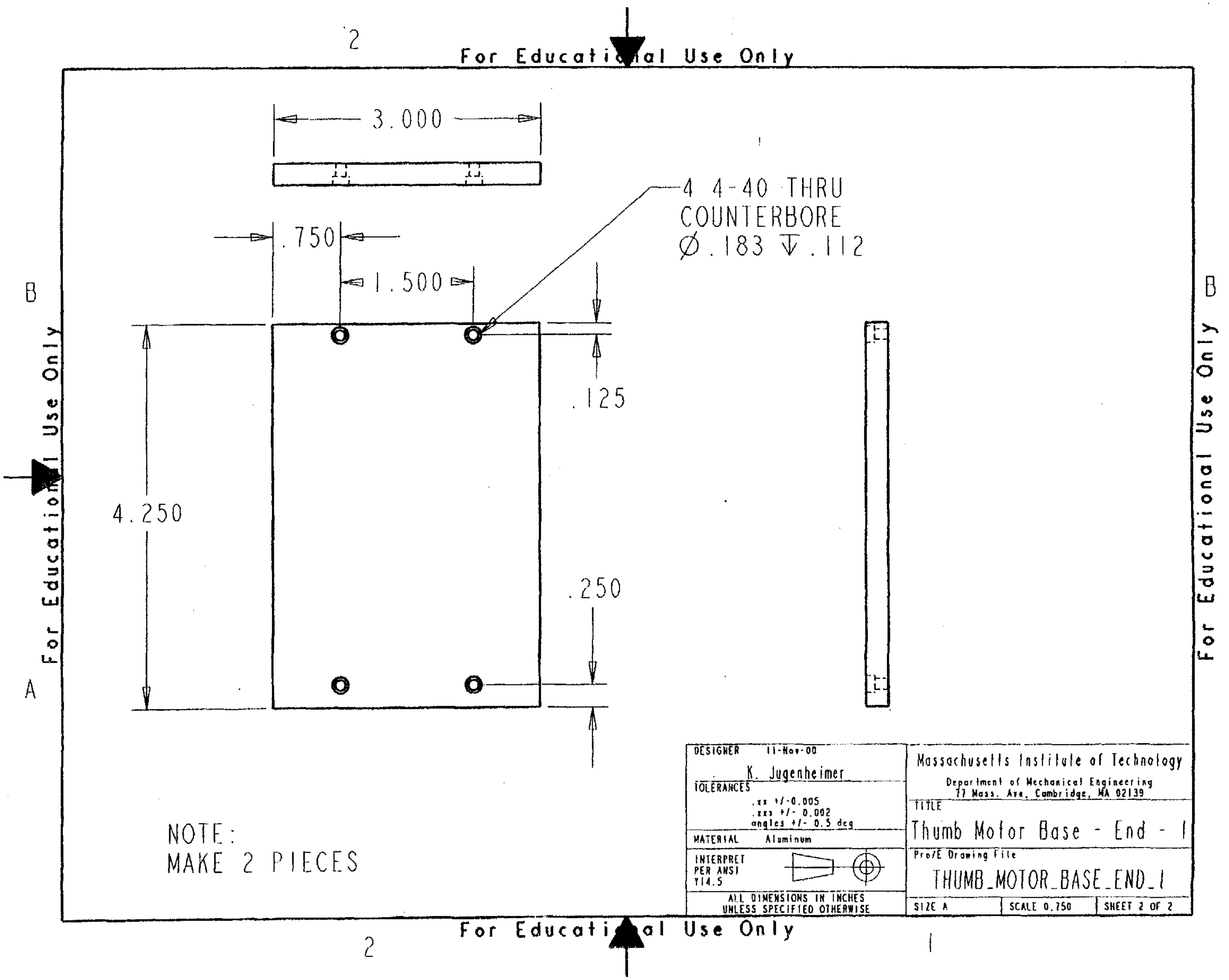
DETAIL MOTOR MOUNT
SCALE 1.500

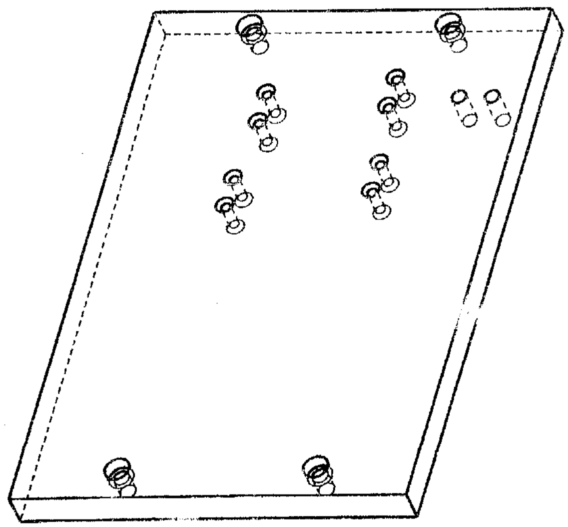
DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Motor Base - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_MOTOR_BASE_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.625 | SHEET 3 OF 4

For Educational Use Only


For Educational Use Only
1.939
1.937
TYP
1.887
1.885
TYP
.044
.042
.695
.690
TYP
4.310
.900
.032
.030
.6250
.6243
TYP
.3750
.3743
TYP
1.063
.250
1.6049
1.6039
.445
.440
TYP
SECTION A-A
SCALE 1.000
1.6049
1.6039
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - Bottom
Pro/E Drawing File
THUMB_MOTOR_BASE_BOTTOM
SIZE A
SCALE 0.625
SHEET 4 OF 4


11-11-00
2
For Educational Use Only
B
A
ISOMETRIC VIEW
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - End - 1
Pro/E Drawing File
THUMB_MOTOR_BASE_END_1
SIZE A
SCALE 1.000
SHEET 1 OF 2
1

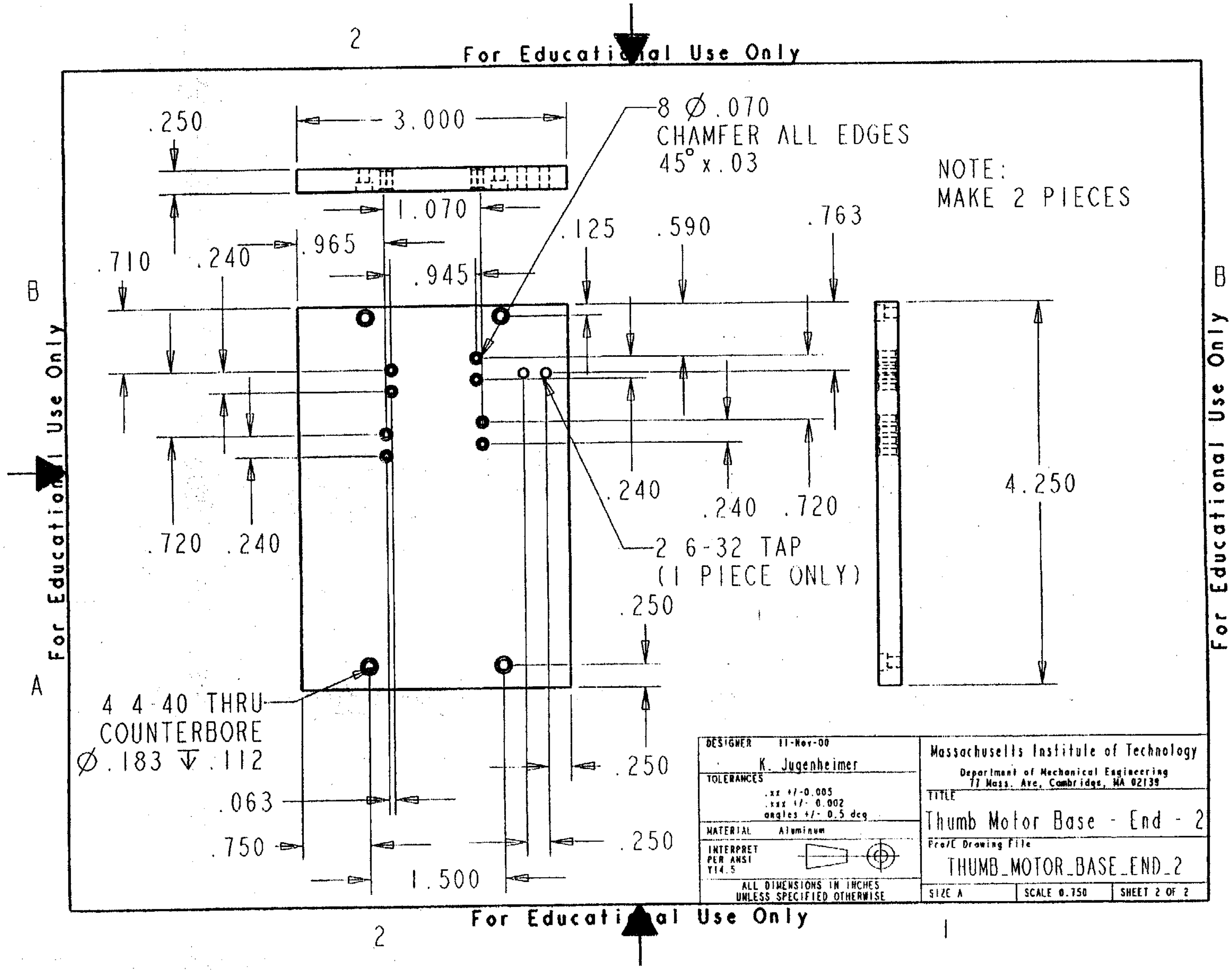

For Educational Use Only
3.000
.750
1.500
4 4-40 THRU
COUNTERBORE
Ø.183 ↧ .112
.125
4.250
.250
NOTE:
MAKE 2 PIECES
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - End - 1
Pro/E Drawing File
THUMB_MOTOR_BASE_END_1
SIZE A
SCALE 0.750
SHEET 2 OF 2



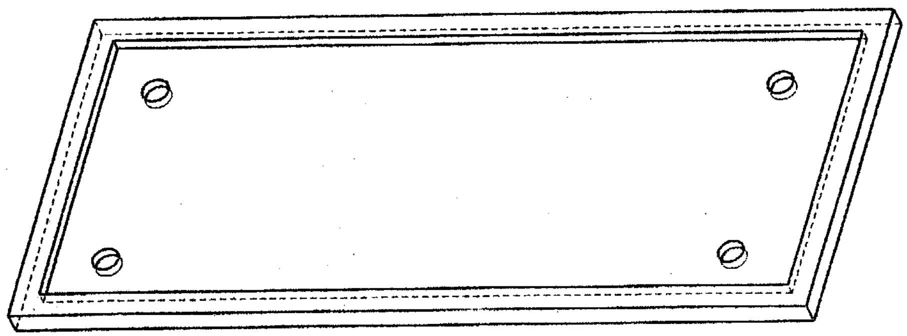
ISOMETRIC VIEW

DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Motor Base - End - 2
MATERIAL Aluminum	Pro/E Drawing File THUMB_MOTOR_BASE_END_2
INTERPRET PER ANSI Y14.5	SIZE A · SCALE 1.000 · SHEET 1 OF 2
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	

For Educational Use Only


For Educational Use Only
2
B
A
.250
3.000
1.070
.965
.945
.710
.240
.720
.240
8 Ø.070
CHAMFER ALL EDGES
45° x .03
NOTE:
MAKE 2 PIECES
.125
.590
.763
.240
.240
.720
2 6-32 TAP
(1 PIECE ONLY)
.250
4.250
4 4-40 THRU
COUNTERBORE
Ø.183 ⩡ .112
.063
.750
1.500
.250
.250
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - End - 2
Pro/E Drawing File
THUMB_MOTOR_BASE_END_2
SIZE A
SCALE 0.750
SHEET 2 OF 2

11-14-00



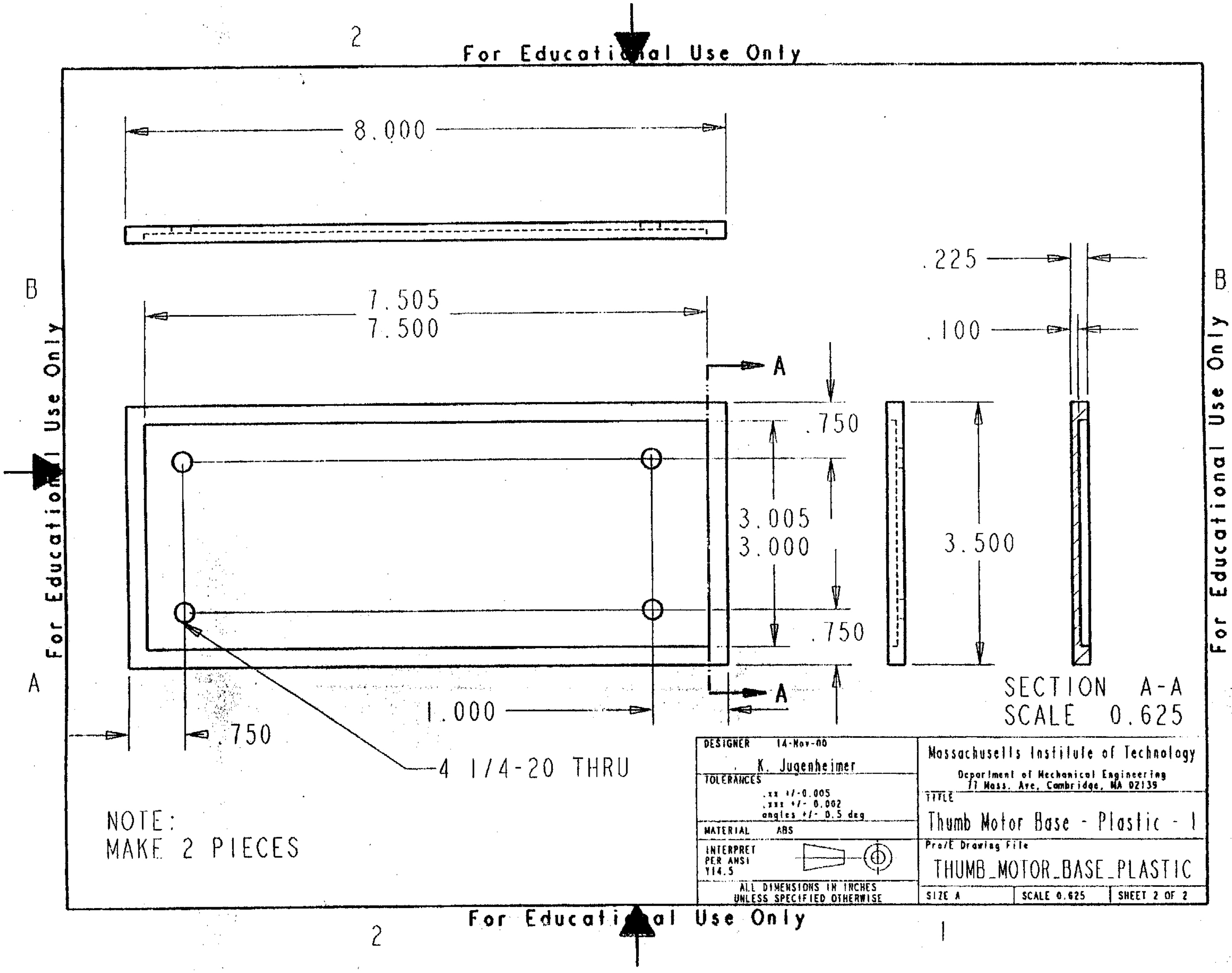
ISOMETRIC VIEW

DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Motor Base - Plastic - 1
MATERIAL ABS	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_MOTOR_BASE_PLASTIC
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.750 | SHEET 1 OF 2

For Educational Use Only

For Educational Use Only

For Educational Use Only

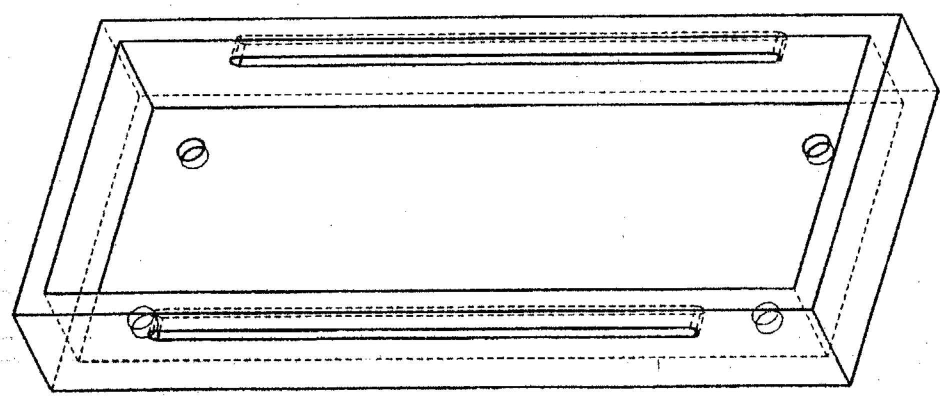


For Educational Use Only
8.000
7.505
7.500
.225
.100
A
.750
3.005
3.000
3.500
.750
A
SECTION A-A
SCALE 0.625
1.000
.750
4 1/4-20 THRU
NOTE:
MAKE 2 PIECES
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL ABS
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - Plastic - 1
Pro/E Drawing File
THUMB_MOTOR_BASE_PLASTIC
SIZE A
SCALE 0.625
SHEET 2 OF 2

11-14-00

2

For Educational Use Only



ISOMETRIC VIEW

B

A

For Educational Use Only

B

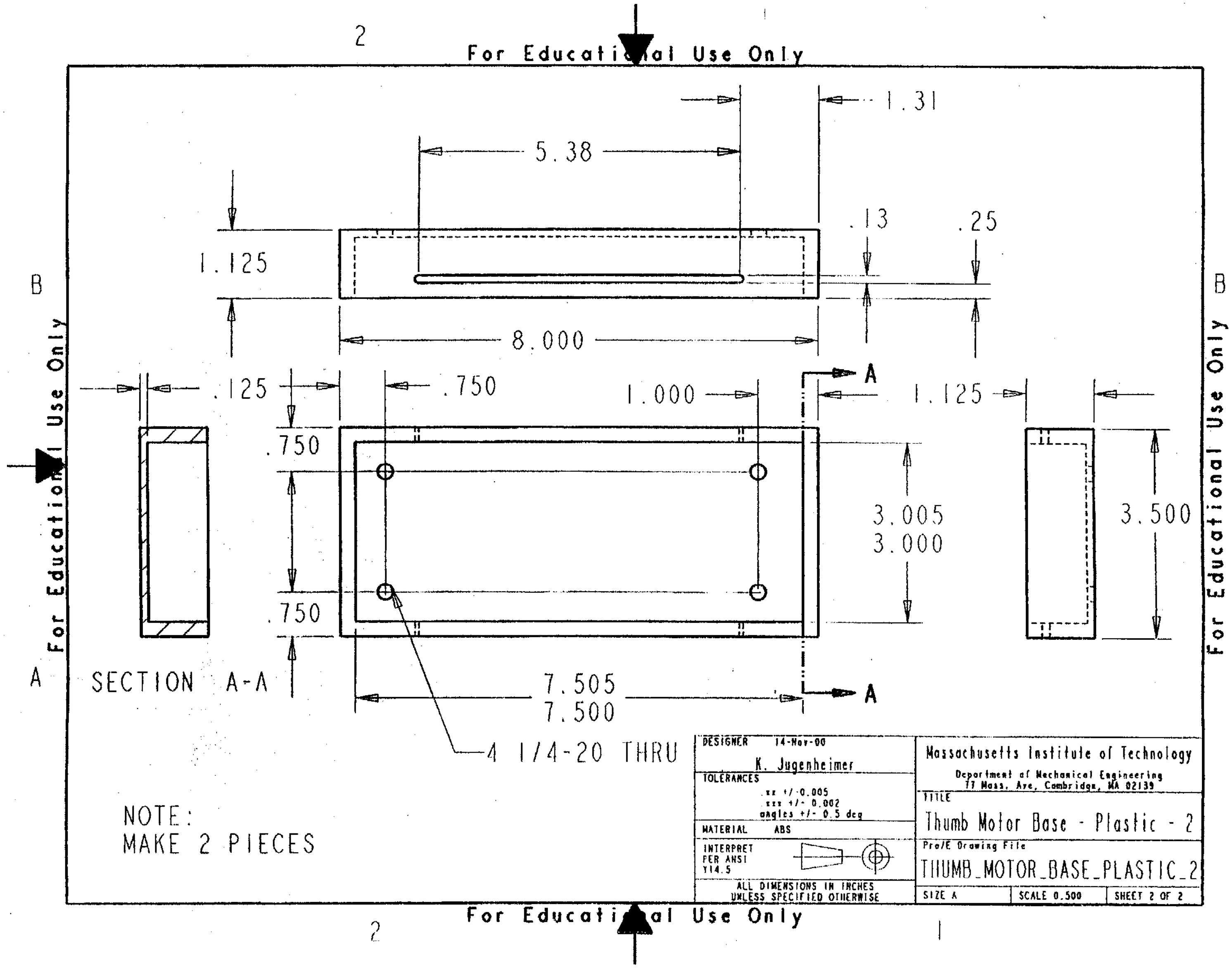
For Educational Use Only

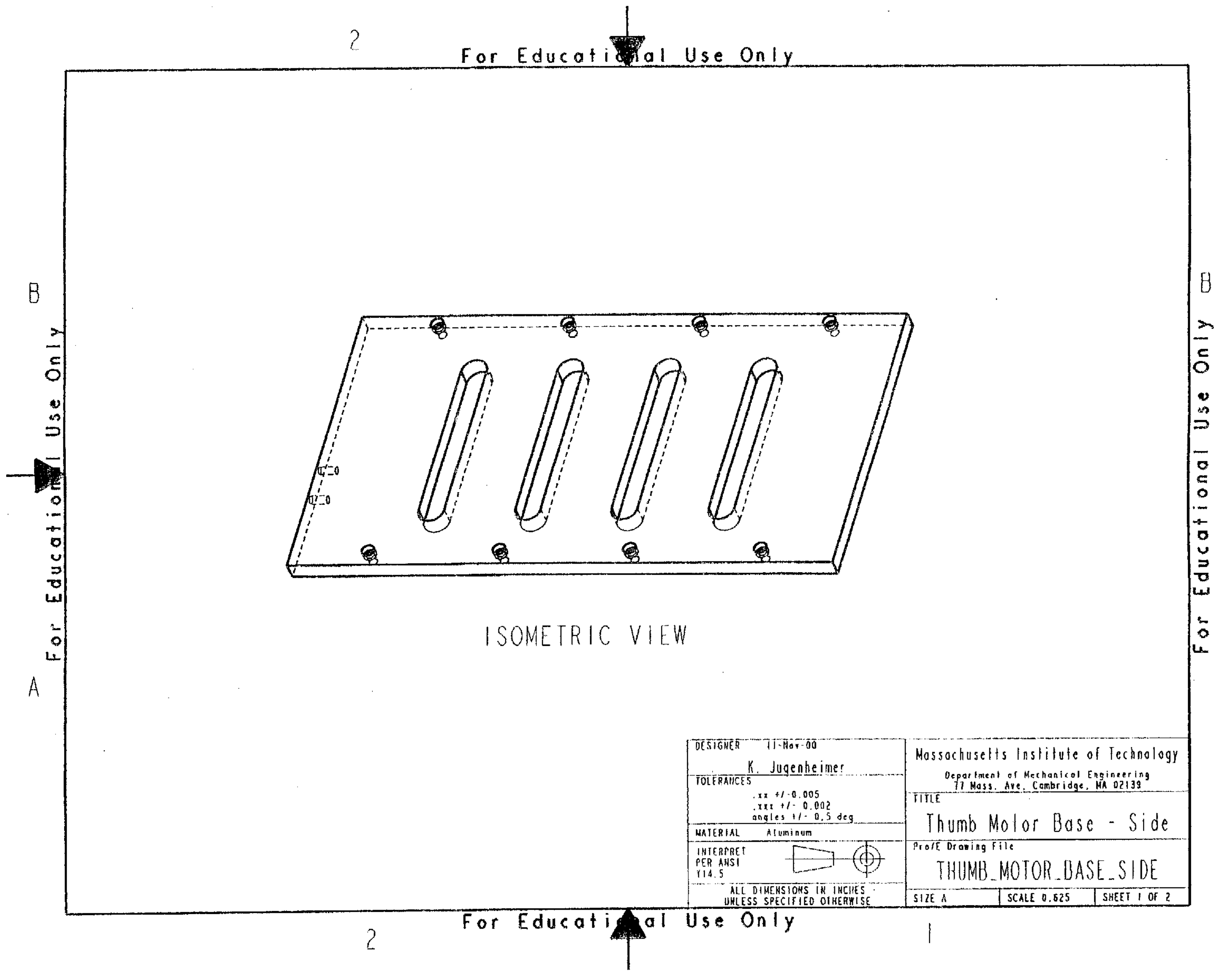
DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Motor Base - Plastic - 2
MATERIAL ABS	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_MOTOR_BASE_PLASTIC_2
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.750 | SHEET 1 OF 2

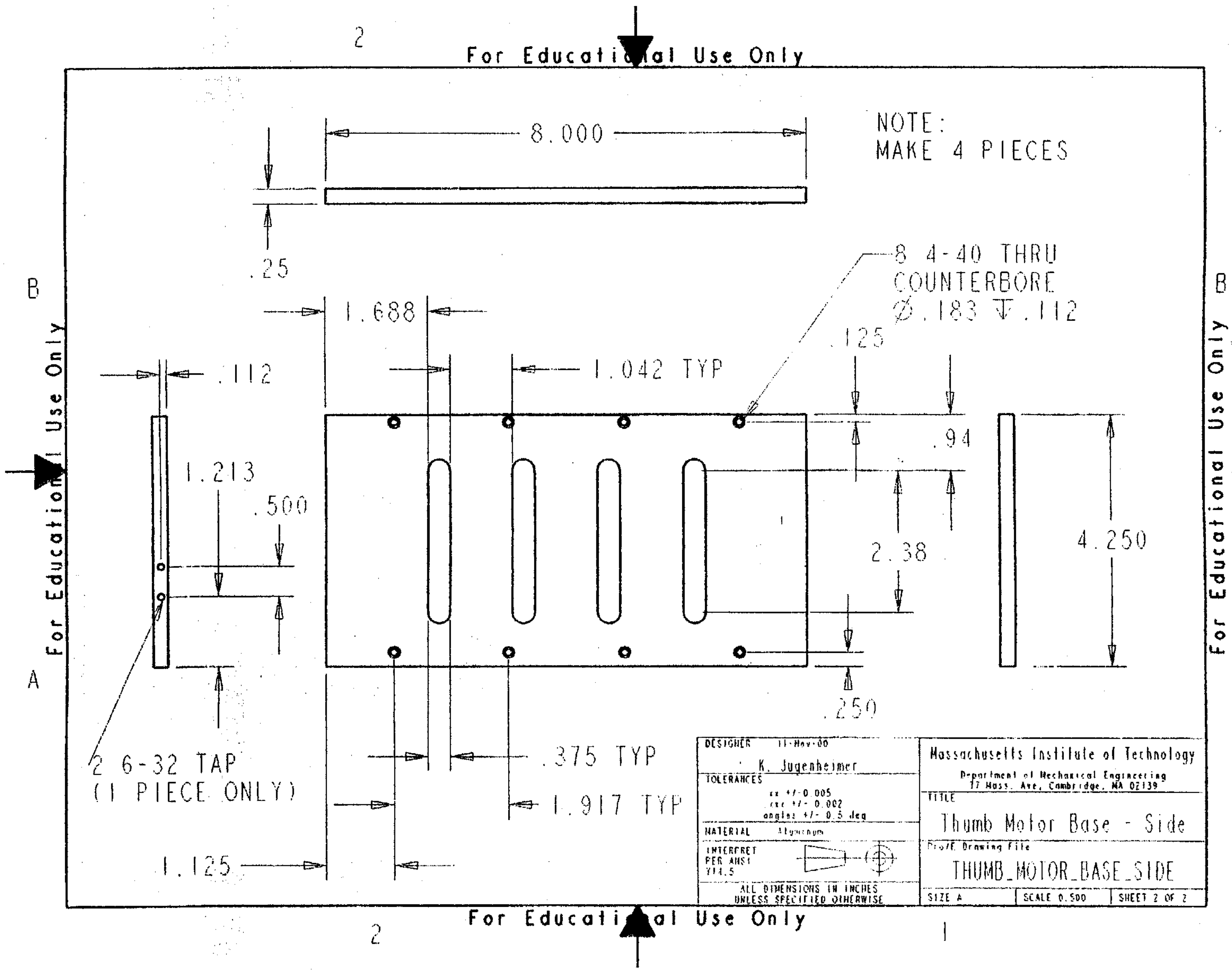
For Educational Use Only

2

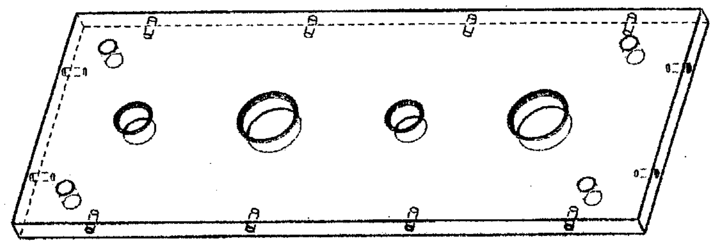
1


For Educational Use Only
5.38
1.31
1.125
.13
.25
8.000
.125
.750
1.000
1.125
A
B
.750
.750
3.005
3.000
3.500
SECTION A-A
7.505
7.500
4 1/4-20 THRU
NOTE:
MAKE 2 PIECES
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL ABS
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - Plastic - 2
Pro/E Drawing File
THUMB_MOTOR_BASE_PLASTIC_2
SIZE A
SCALE 0.500
SHEET 2 OF 2


For Educational Use Only
2
B
A
ISOMETRIC VIEW
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Molor Base - Side
Pro/E Drawing File
THUMB_MOTOR_BASE_SIDE
SIZE A
SCALE 0.625
SHEET 1 OF 2
1

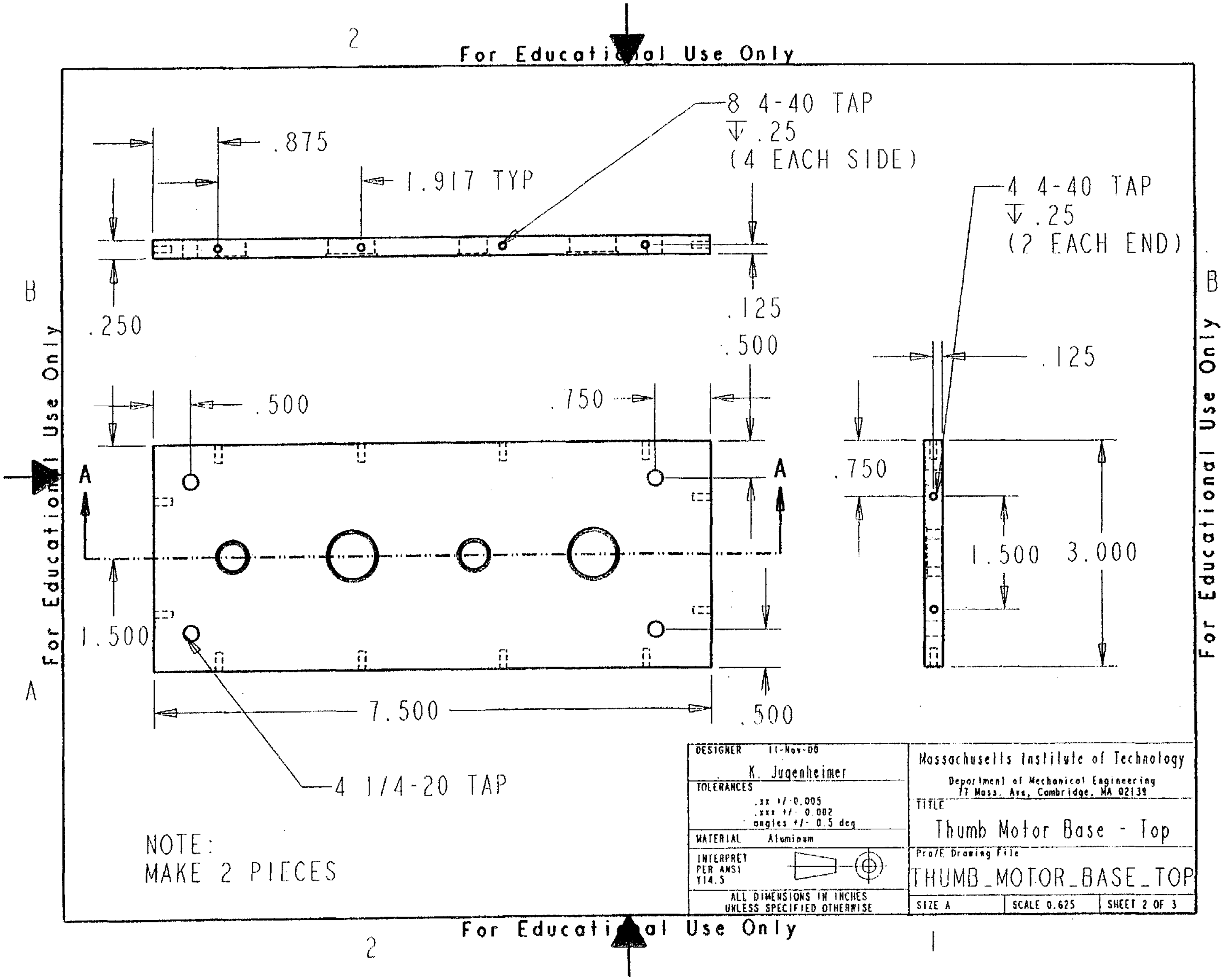

2
For Educational Use Only
8.000
NOTE:
MAKE 4 PIECES
.25
B
8 4-40 THRU
COUNTERBORE
∅.183 ↧.112
1.688
.125
.112
1.042 TYP
.94
1.213
.500
2.38
4.250
A
.250
2 6-32 TAP
(1 PIECE ONLY)
.375 TYP
1.917 TYP
1.125
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
xx +/-0.005
xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - Side
Pro/E Drawing File
THUMB_MOTOR_BASE_SIDE
SIZE A
SCALE 0.500
SHEET 2 OF 2
1

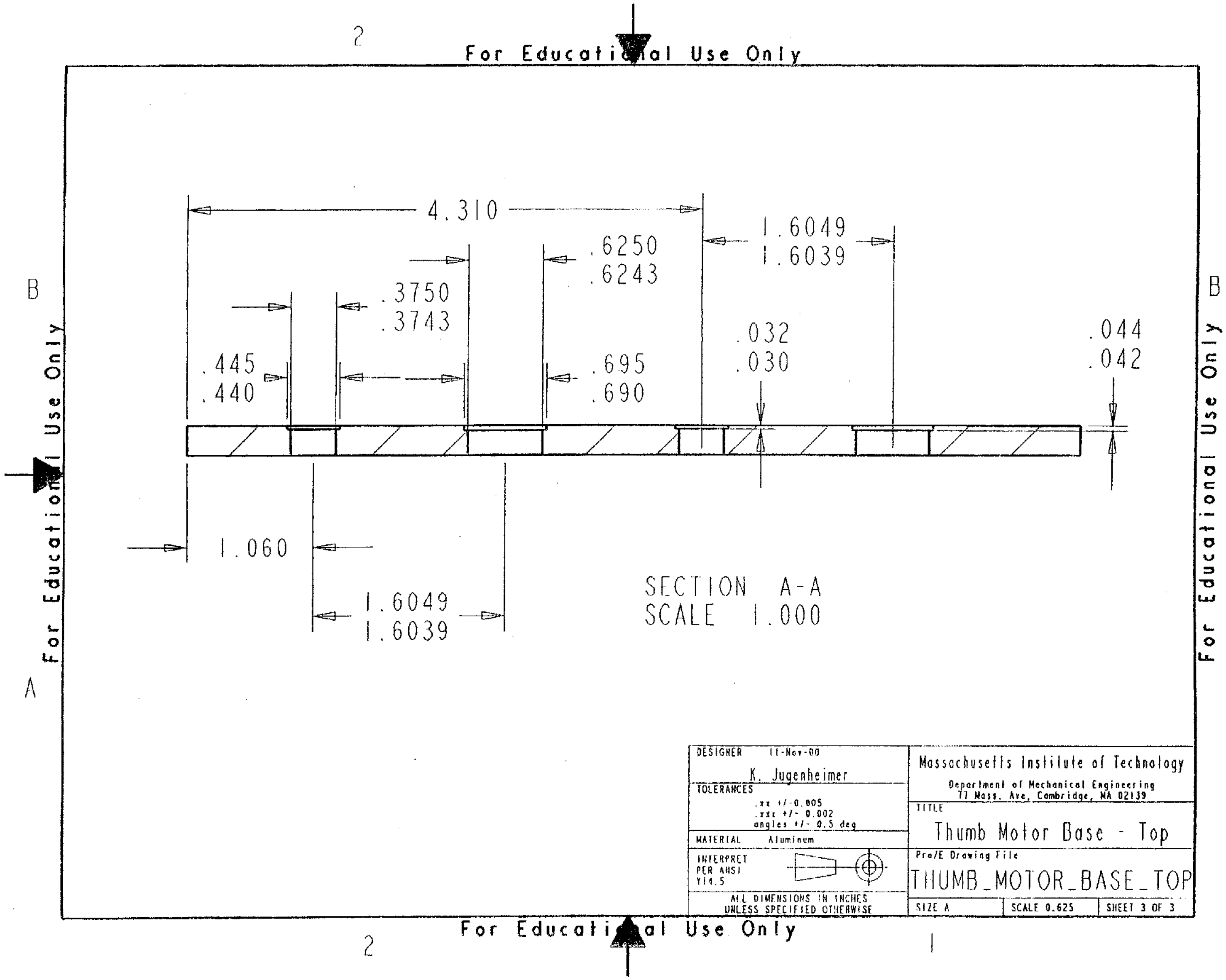
11-11-00



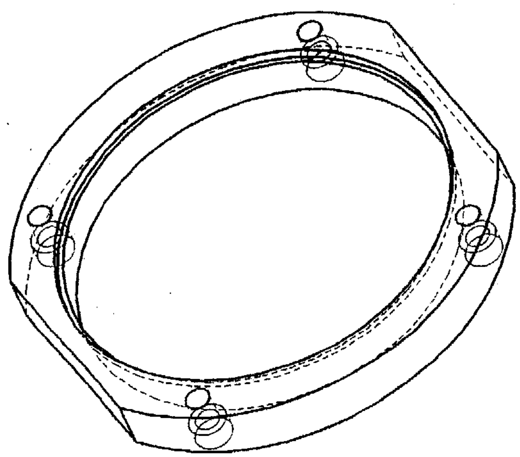
ISOMETRIC VIEW

DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES xx +/- 0.005 xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Motor Base - Top
MATERIAL Aluminum	ProE Drawing File
INTERPRET PER ANSI Y14.5	THUMB_MOTOR_BASE_TOP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.625 | SHEET 1 OF 3


For Educational Use Only
8 4-40 TAP
.25
(4 EACH SIDE)
.875
1.917 TYP
4 4-40 TAP
.25
(2 EACH END)
.250
.125
.500
.125
.500
.750
A
A
.750
1.500
3.000
1.500
7.500
.500
4 1/4-20 TAP
NOTE:
MAKE 2 PIECES
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - Top
Pro/E Drawing File
THUMB_MOTOR_BASE_TOP
SIZE A
SCALE 0.625
SHEET 2 OF 3


For Educational Use Only
4.310
1.6049
1.6039
.6250
.6243
.3750
.3743
.445
.440
.695
.690
.032
.030
.044
.042
1.060
1.6049
1.6039
SECTION A-A
SCALE 1.000
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base - Top
Pro/E Drawing File
THUMB_MOTOR_BASE_TOP
SIZE A
SCALE 0.625
SHEET 3 OF 3

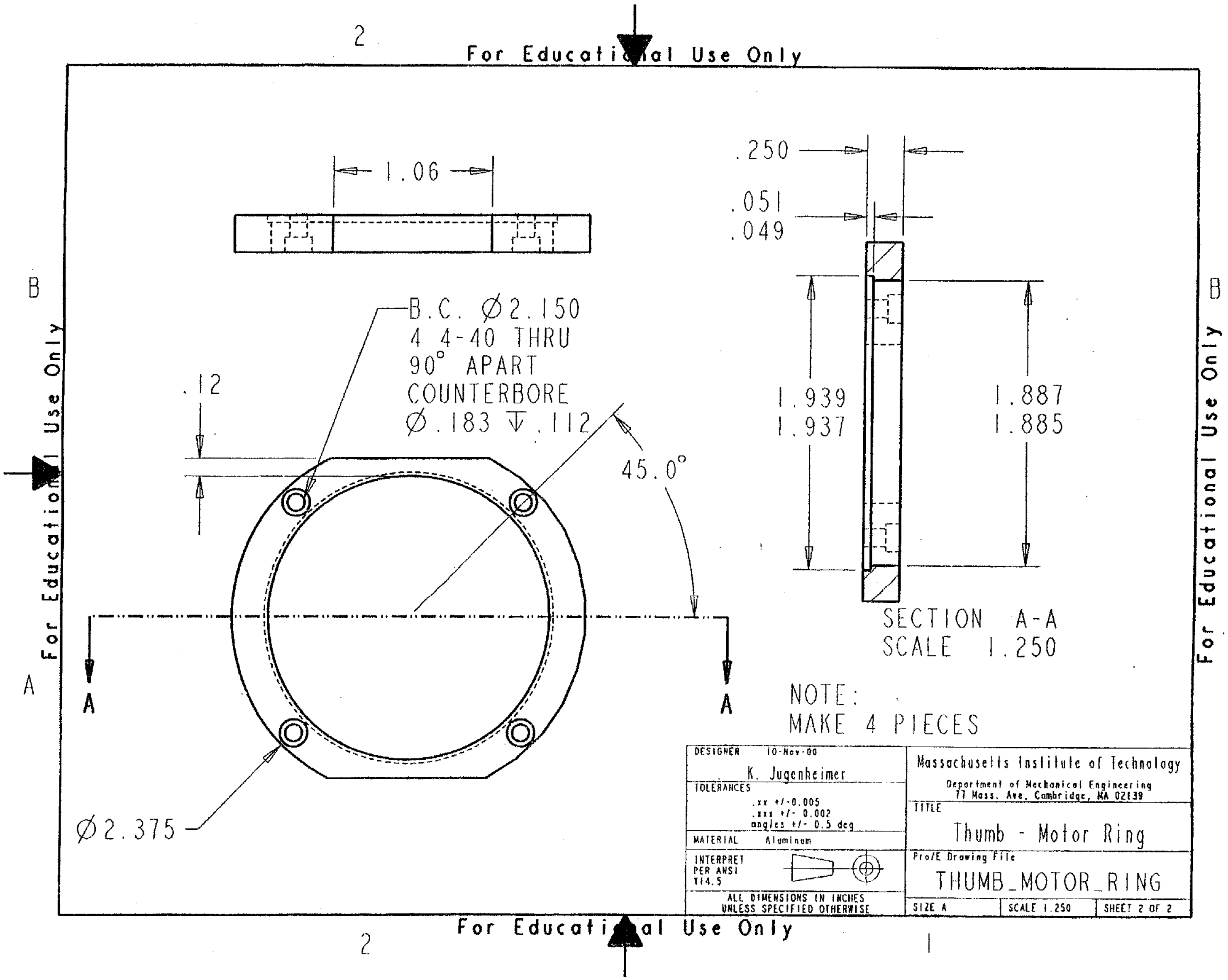
11-10-00

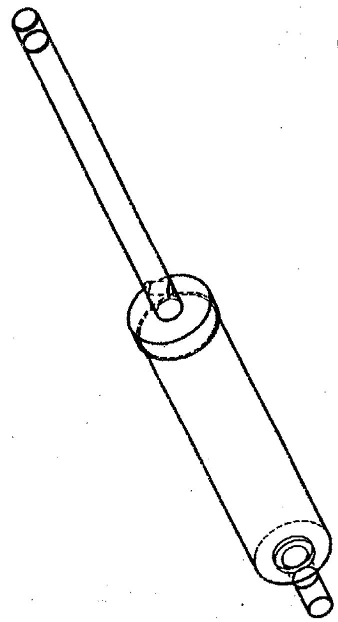


ISOMETRIC VIEW

DESIGNER 10-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - Motor Ring
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_MOTOR_RING
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.500 | SHEET 1 OF 2

For Educational Use Only
For Educational Use Only
For Educational Use Only

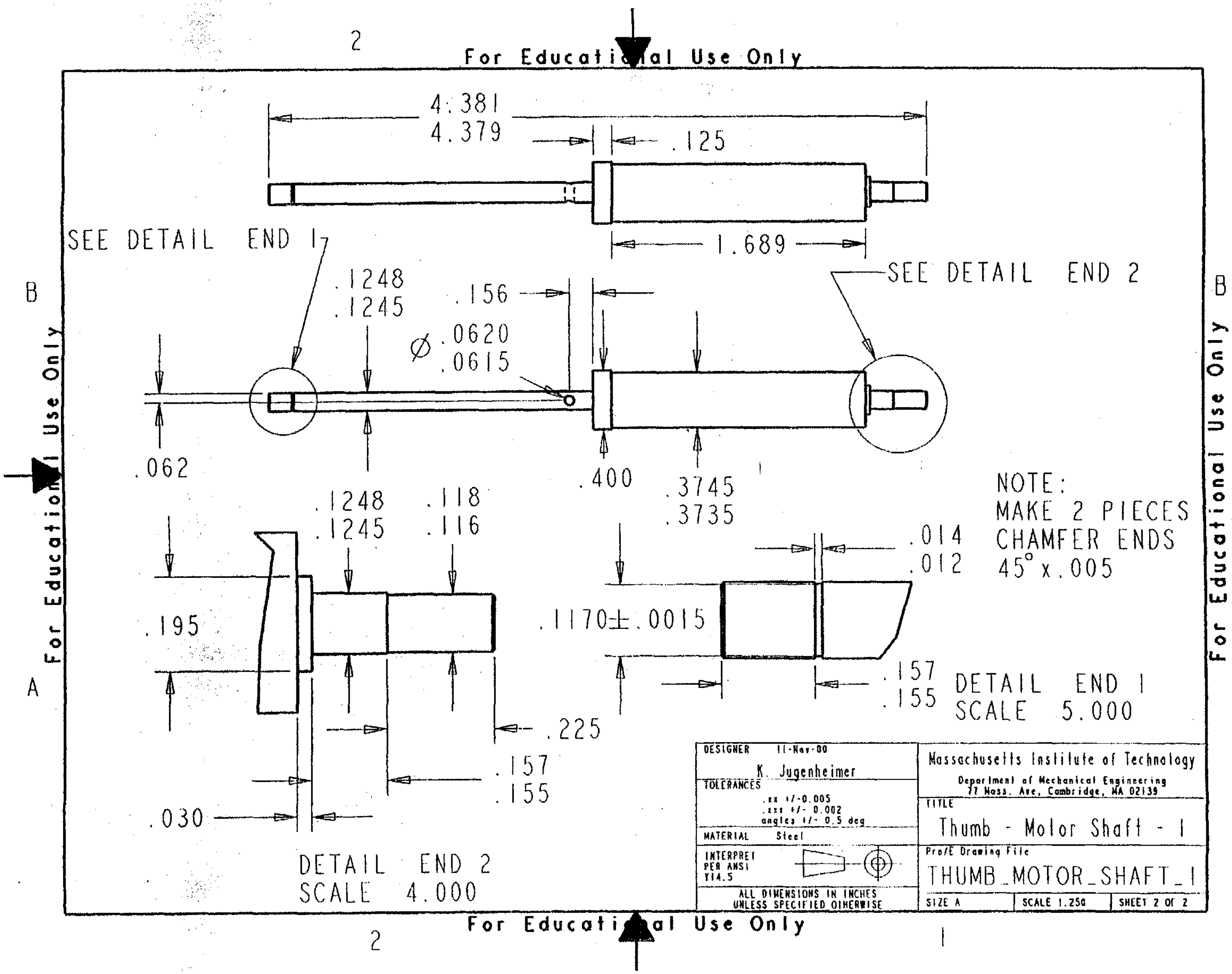

For Educational Use Only
1.06
.250
.051
.049
B.C. Ø2.150
4 4-40 THRU
90° APART
COUNTERBORE
Ø.183 ↧.112
.12
45.0°
1.939
1.937
1.887
1.885
SECTION A-A
SCALE 1.250
A
A
NOTE:
MAKE 4 PIECES
Ø2.375
DESIGNER 10-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - Motor Ring
Pro/E Drawing File
THUMB_MOTOR_RING
SIZE A
SCALE 1.250
SHEET 2 OF 2

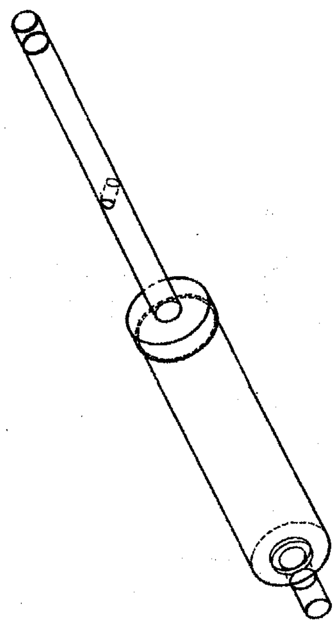


ISOMETRIC VIEW

DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - Motor Shaft - 1
MATERIAL Steel	
INTERPRET PER ANSI Y14.5	Pro/C Drawing File THUMB_MOTOR_SHAFT_1
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.500 | SHEET 1 OF 2

For Educational Use Only

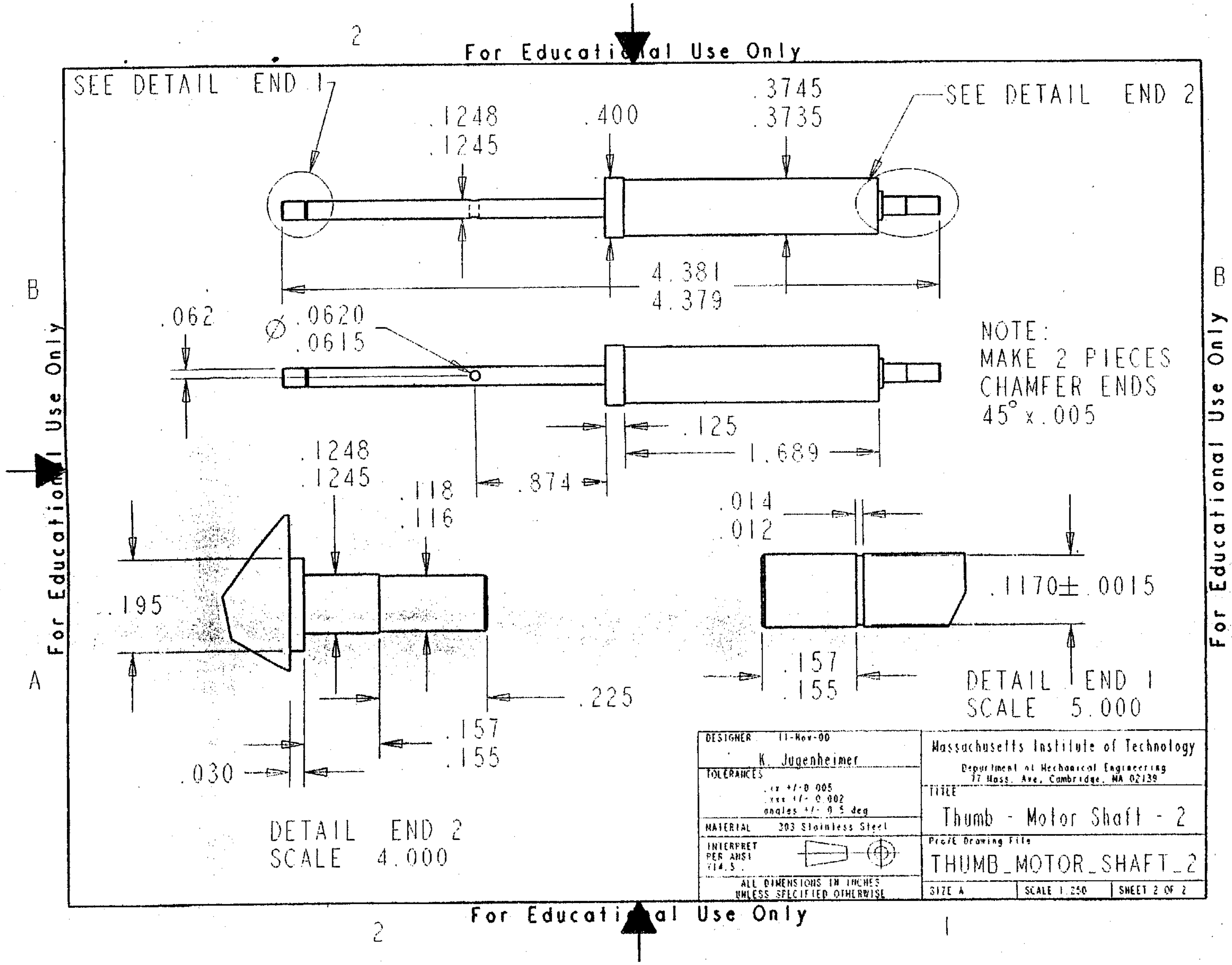

For Educational Use Only
4.381
4.379
.125
1.689
SEE DETAIL END 1
SEE DETAIL END 2
.1248
.1245
.156
∅ .0620
.0615
.062
.400
.3745
.3735
NOTE:
MAKE 2 PIECES
CHAMFER ENDS
45° x .005
.1248
.1245
.118
.116
.195
.225
.157
.155
.030
DETAIL END 2
SCALE 4.000
.1170±.0015
.014
.012
.157
.155
DETAIL END 1
SCALE 5.000
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Steel
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - Motor Shaft - 1
Pro/E Drawing File
THUMB_MOTOR_SHAFT_1
SIZE A
SCALE 1.250
SHEET 2 OF 2

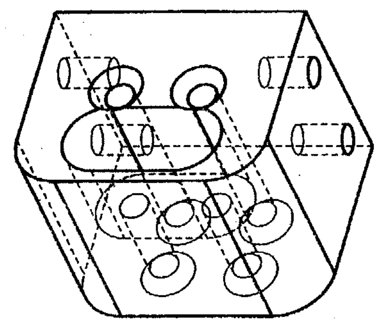


ISOMETRIC VIEW

DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - Motor Shaft - 2
MATERIAL 303 Stainless Steel	Pro/E Drawing File THUMB_MOTOR_SHAFT_2
INTERPRET PER ANSI Y14.5	
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.500 | SHEET 1 OF 2

For Educational Use Only

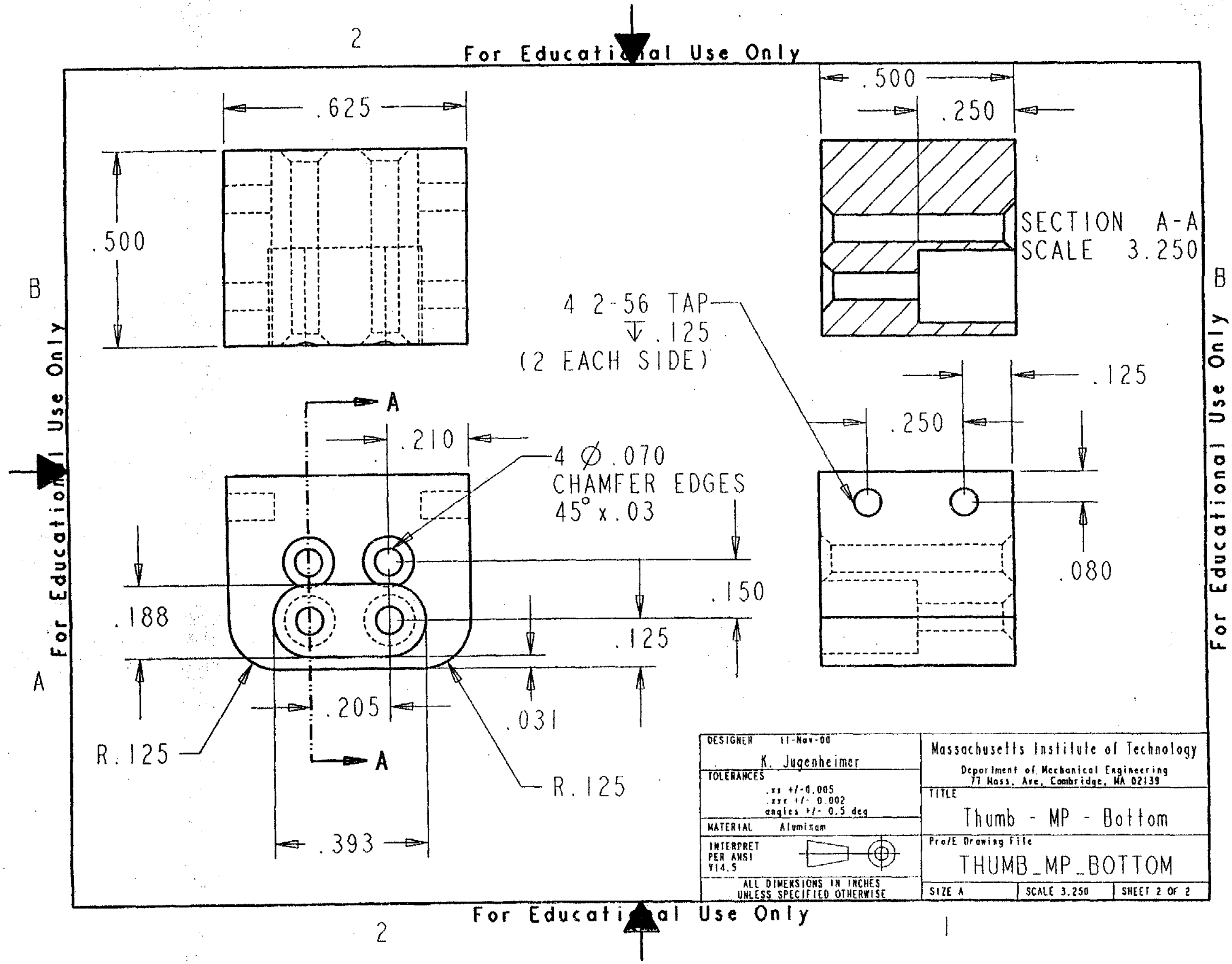

For Educational Use Only
SEE DETAIL END 1
.1248
.1245
.400
.3745
.3735
SEE DETAIL END 2
4.381
4.379
.062
⌀.0620
.0615
NOTE:
MAKE 2 PIECES
CHAMFER ENDS
45° x .005
.125
1.689
.874
.1248
.1245
.118
.116
.195
.225
.157
.155
.030
DETAIL END 2
SCALE 4.000
.014
.012
.1170±.0015
.157
.155
DETAIL END 1
SCALE 5.000
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/-0.002
angles +/-0.5 deg
MATERIAL 303 Stainless Steel
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - Motor Shaft - 2
Pro/E Drawing File
THUMB_MOTOR_SHAFT_2
SIZE A
SCALE 1.250
SHEET 2 OF 2



ISOMETRIC VIEW

DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - MP - Bottom
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_MP_BOTTOM
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 3.000 | SHEET 1 OF 2

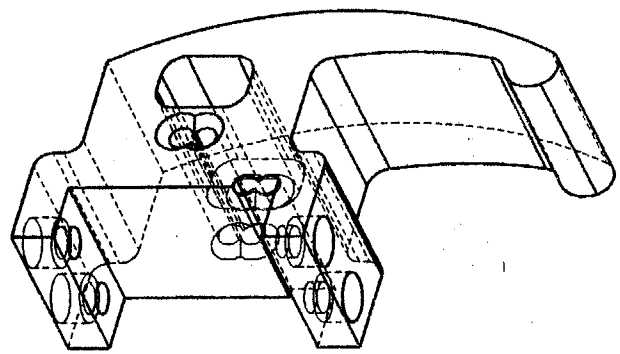
For Educational Use Only



For Educational Use Only
.625
.500
.500
.250
SECTION A-A
SCALE 3.250
4 2-56 TAP
⊽ .125
(2 EACH SIDE)
.125
.250
.080
A
.210
4 Ø .070
CHAMFER EDGES
45° x .03
.150
.188
.125
.205
.031
R.125
R.125
.393
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Thumb - MP - Bottom
Pro/E Drawing File
THUMB_MP_BOTTOM
SIZE A
SCALE 3.250
SHEET 2 OF 2

2

B



ISOMETRIC VIEW

A

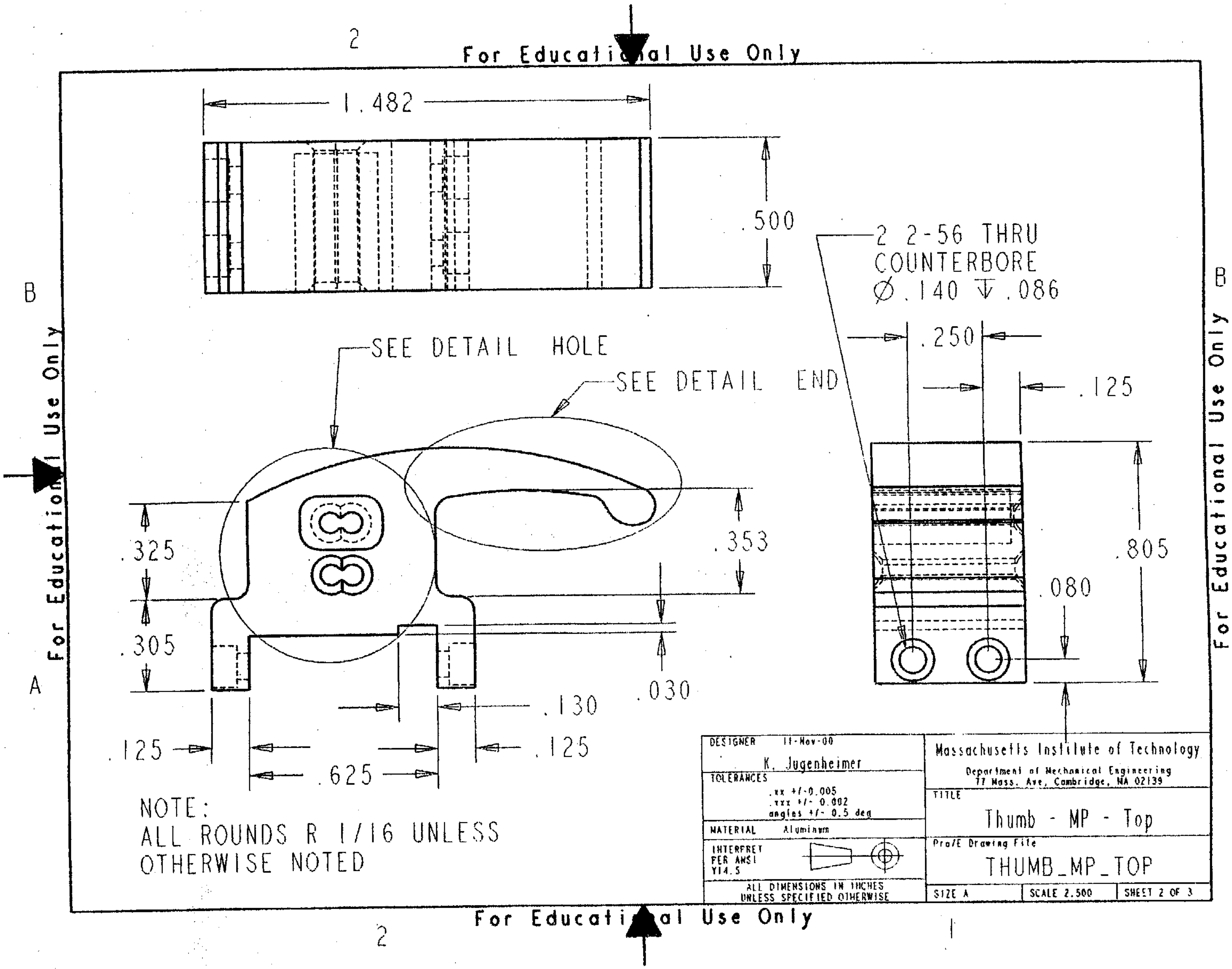
DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb - MP - Top
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_MP_TOP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 2.500 · SHEET 1 OF 3

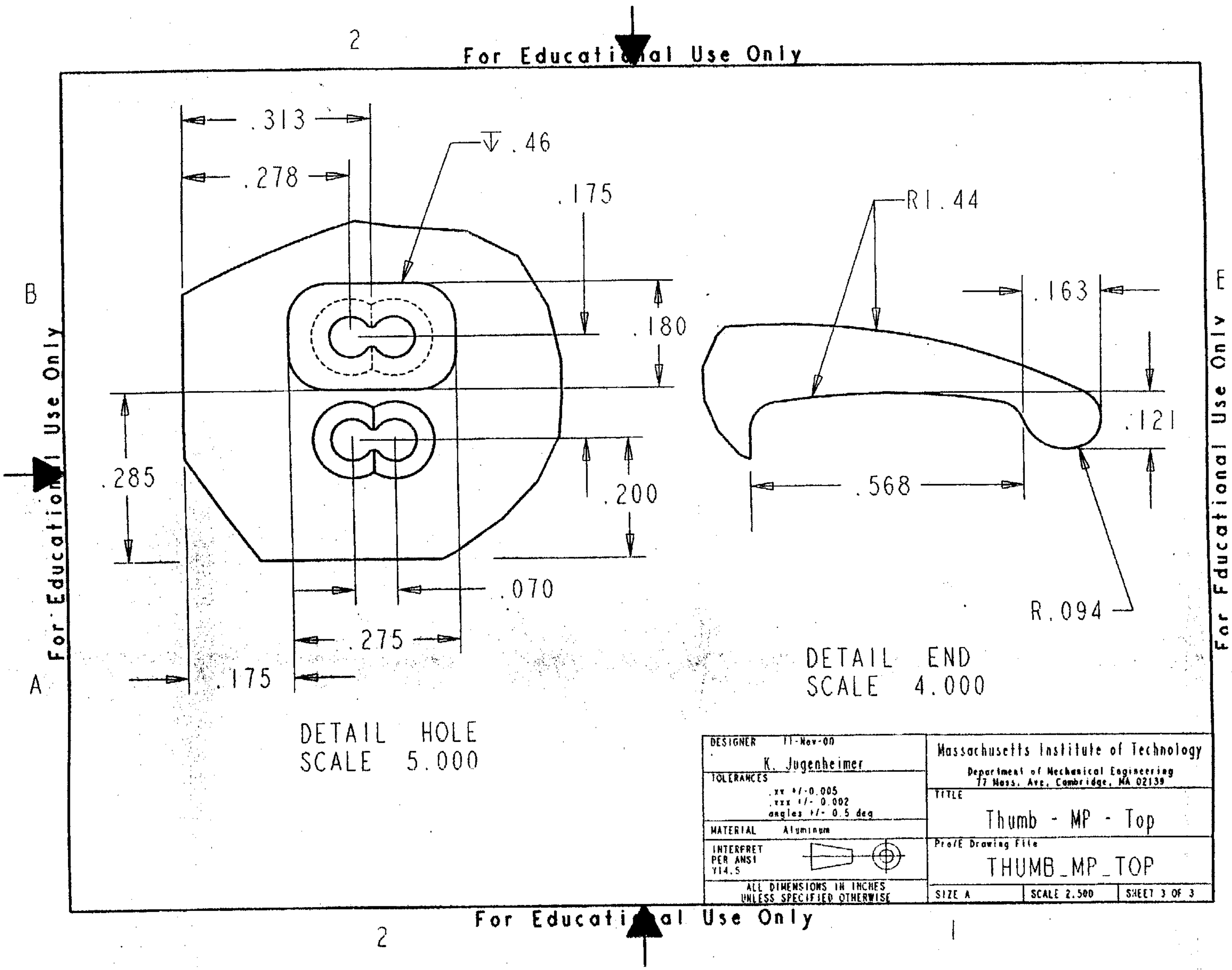
For Educational Use Only

For Educational Use Only

For Educational Use Only

2 1


For Educational Use Only
1.482
.500
2 2-56 THRU
COUNTERBORE
Ø.140 ↧.086
SEE DETAIL HOLE
SEE DETAIL END
.250
.125
.325
.353
.805
.080
.305
.030
.130
.125
.625
.125
NOTE:
ALL ROUNDS R 1/16 UNLESS
OTHERWISE NOTED
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb - MP - Top
Pro/E Drawing File
THUMB_MP_TOP
SIZE A
SCALE 2.500
SHEET 2 OF 3


For Educational Use Only
2
B
A
E
.313
.278
.46
.175
.180
.285
.200
.070
.275
.175
DETAIL HOLE
SCALE 5.000
R1.44
.163
.121
.568
R.094
DETAIL END
SCALE 4.000
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Thumb - MP - Top
Pro/E Drawing File
THUMB_MP_TOP
SIZE A
SCALE 2.500
SHEET 3 OF 3

11-14-00

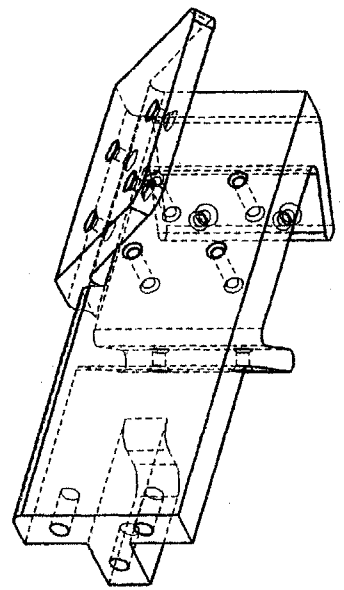
2

B

For Educational Use Only

For Educational Use Only

A



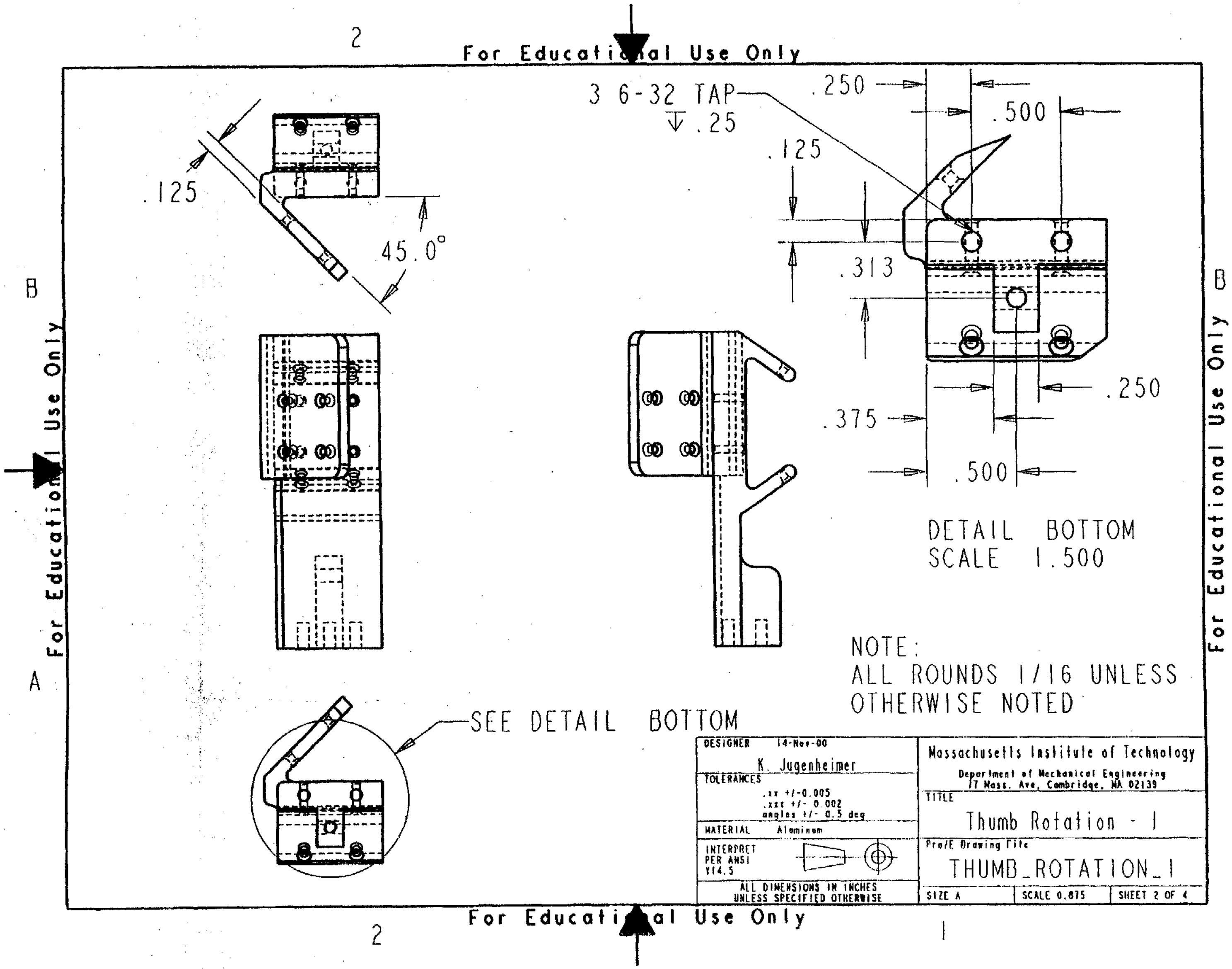
ISOMETRIC VIEW

DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Rotation - 1
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_ROTATION_1
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.250 | SHEET 1 OF 4

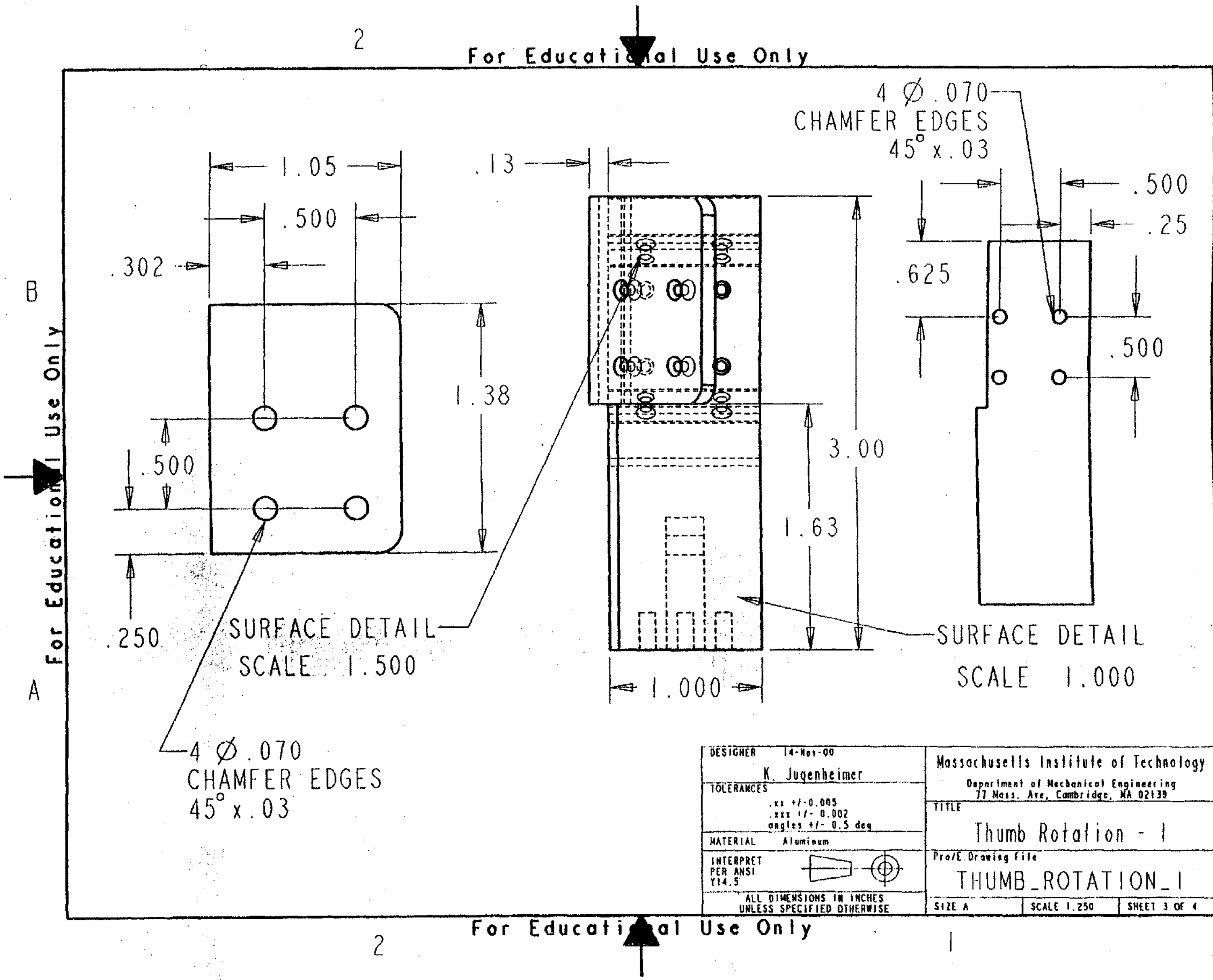
For Educational Use Only

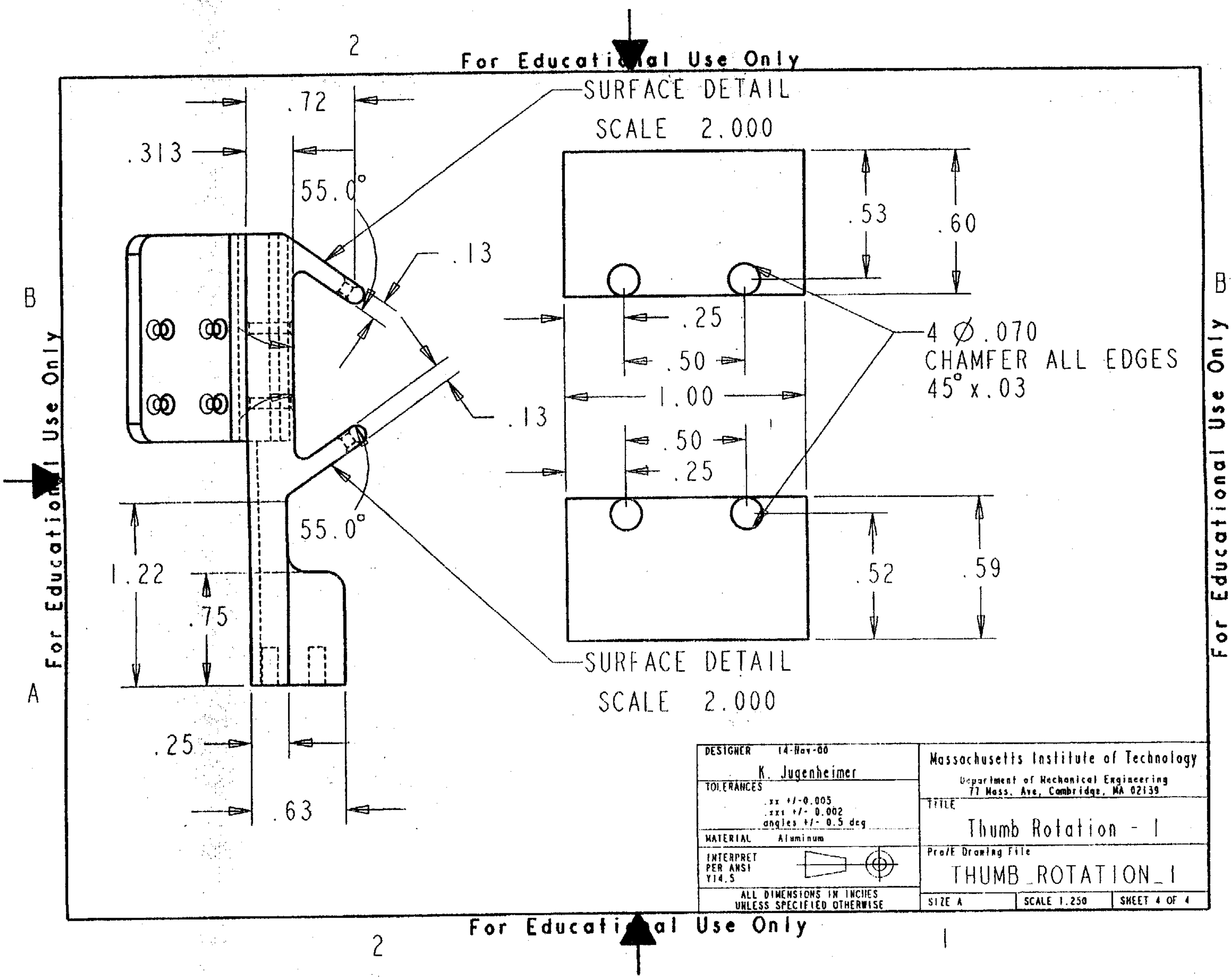
2

1



For Educational Use Only
3 6-32 TAP
.25
.250
.500
.125
.125
45.0°
.313
.250
.375
.500
DETAIL BOTTOM
SCALE 1.500
NOTE:
ALL ROUNDS 1/16 UNLESS
OTHERWISE NOTED
SEE DETAIL BOTTOM
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Rotation - 1
Pro/E Drawing File
THUMB_ROTATION_1
SIZE A
SCALE 0.875
SHEET 2 OF 4


For Educational Use Only
4 Ø .070
CHAMFER EDGES
45° x .03
1.05
.500
.302
.13
.500
.25
.625
.500
1.38
.500
3.00
1.63
.250
SURFACE DETAIL
SCALE 1.500
SURFACE DETAIL
SCALE 1.000
1.000
4 Ø .070
CHAMFER EDGES
45° x .03
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Rotation - I
Pro/E Drawing File
THUMB_ROTATION_I
SIZE A
SCALE 1.250
SHEET 3 OF 4


For Educational Use Only
SURFACE DETAIL
SCALE 2.000
.72
.313
55.0°
.13
.53
.60
.25
.50
1.00
4 ∅.070
CHAMFER ALL EDGES
45° x .03
.13
.50
.25
55.0°
1.22
.75
.52
.59
SURFACE DETAIL
SCALE 2.000
.25
.63
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Rotation - 1
Pro/E Drawing File
THUMB_ROTATION_1
SIZE A
SCALE 1.250
SHEET 4 OF 4
For Educational Use Only

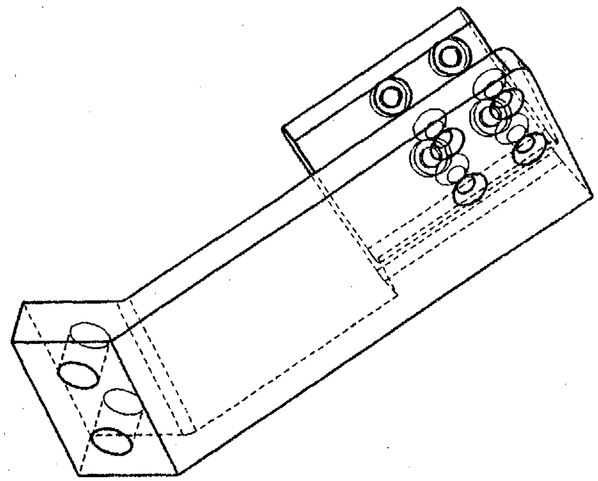
11-14-00

2

For Educational Use Only

B

For Educational Use Only



ISOMETRIC VIEW

A

DESIGNER 14-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Thumb Rotation - 2
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File THUMB_ROTATION_2
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 4

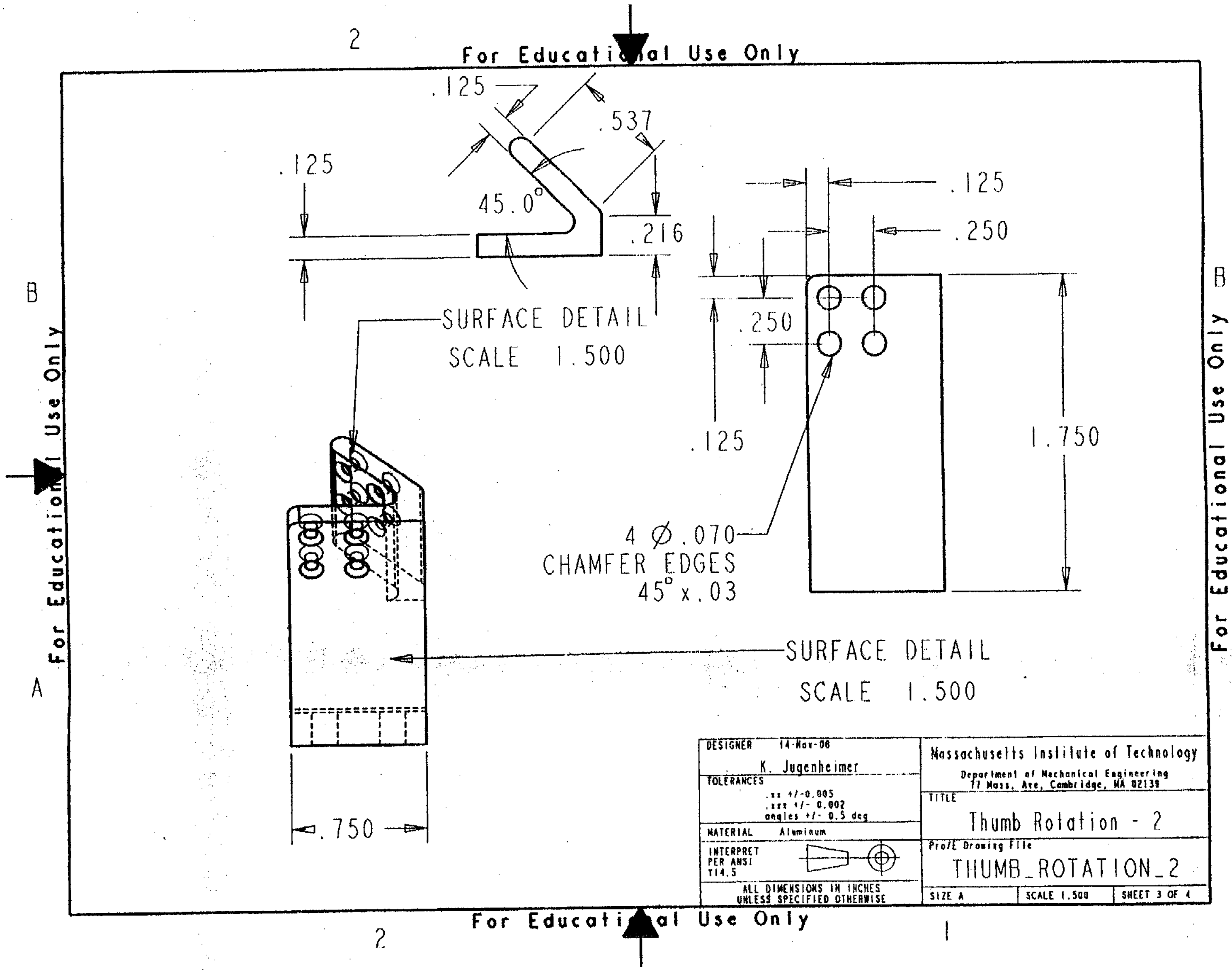
For Educational Use Only

B

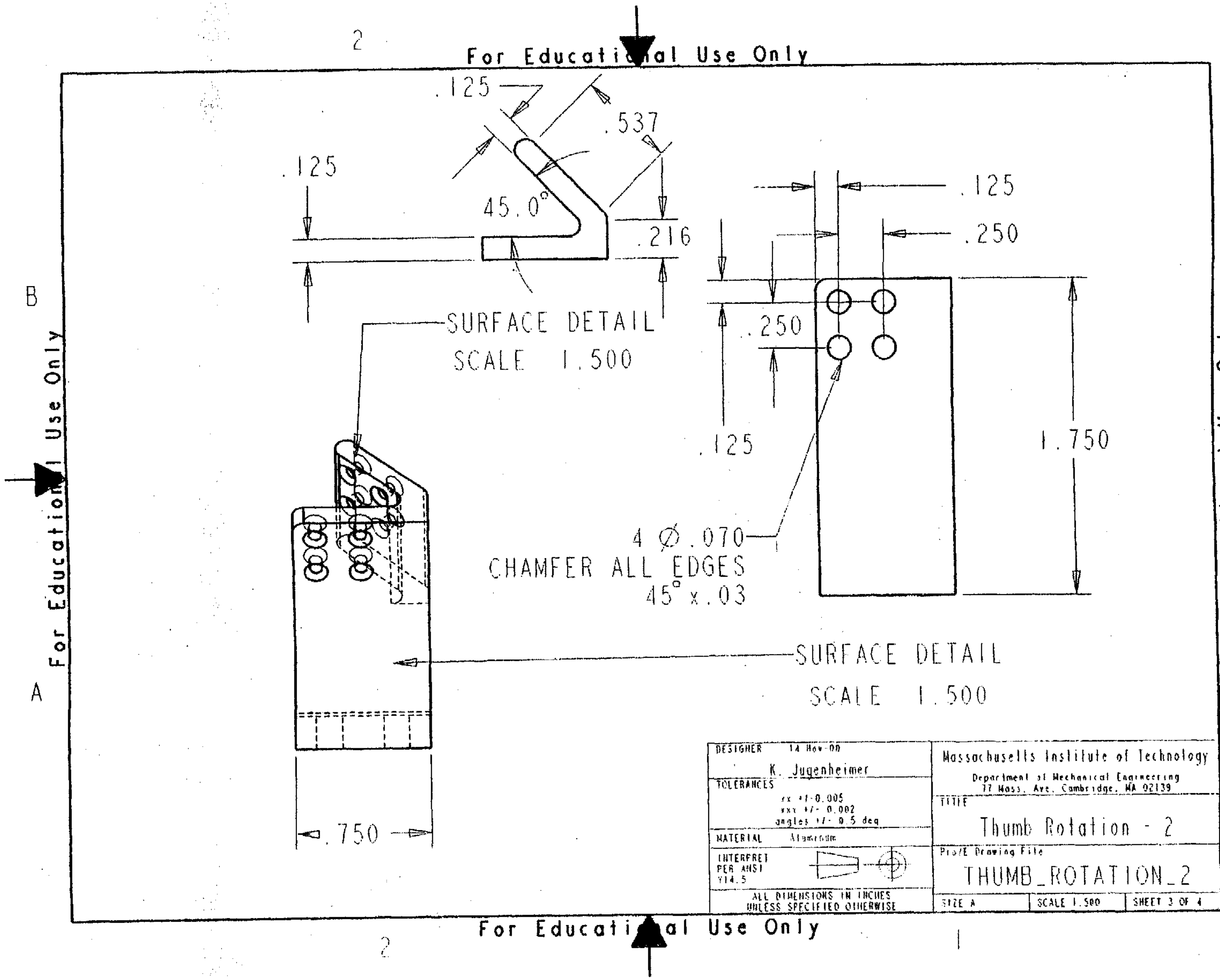
For Educational Use Only

2

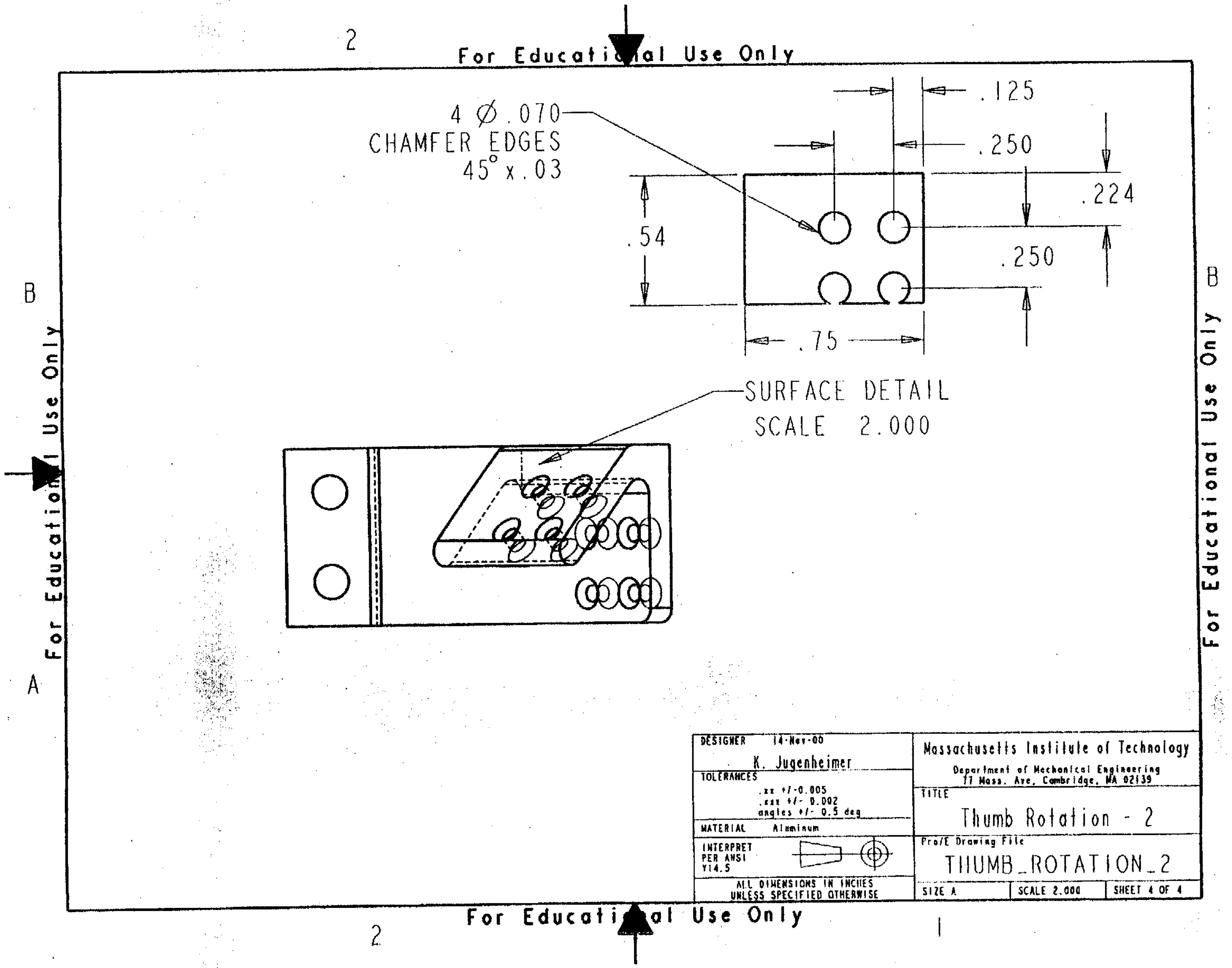
1

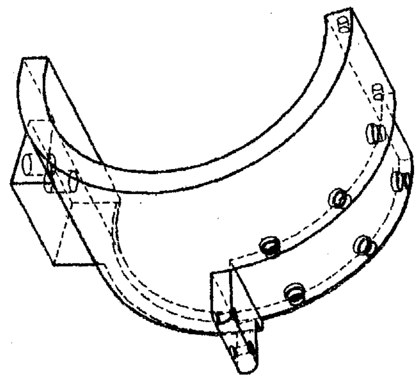


For Educational Use Only
.125
.537
.125
45.0°
.216
SURFACE DETAIL
SCALE 1.500
.125
.250
.250
.125
1.750
4 Ø .070
CHAMFER EDGES
45° x .03
SURFACE DETAIL
SCALE 1.500
.750
DESIGNER 14-Nov-06
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Rotation - 2
Pro/E Drawing File
THUMB_ROTATION_2
SIZE A
SCALE 1.500
SHEET 3 OF 4



For Educational Use Only
.125
.537
.125
45.0°
.216
SURFACE DETAIL
SCALE 1.500
.125
.250
.250
.125
1.750
4 ∅ .070
CHAMFER ALL EDGES
45° x .03
SURFACE DETAIL
SCALE 1.500
.750
DESIGNER 14 Nov-00
K. Jugenheimer
TOLERANCES
xx +/-0.005
xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL
INTERPRET
PER ANSI
Y14.5
ALL DIMENSIONS IN INCHES
UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Thumb Rotation - 2
Pro/E Drawing File
THUMB_ROTATION_2
SIZE A
SCALE 1.500
SHEET 3 OF 4


For Educational Use Only
2
B
A
4 Ø .070
CHAMFER EDGES
45° x .03
.125
.250
.224
.250
.54
.75
SURFACE DETAIL
SCALE 2.000
DESIGNER 14-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Thumb Rotation - 2
Pro/E Drawing File
THUMB_ROTATION_2
SIZE A
SCALE 2.000
SHEET 4 OF 4
1



ISOMETRIC VIEW

DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Wrist Cradle - Base
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File WRIST_CRADLE_BASE
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 0.750 | SHEET 1 OF 3

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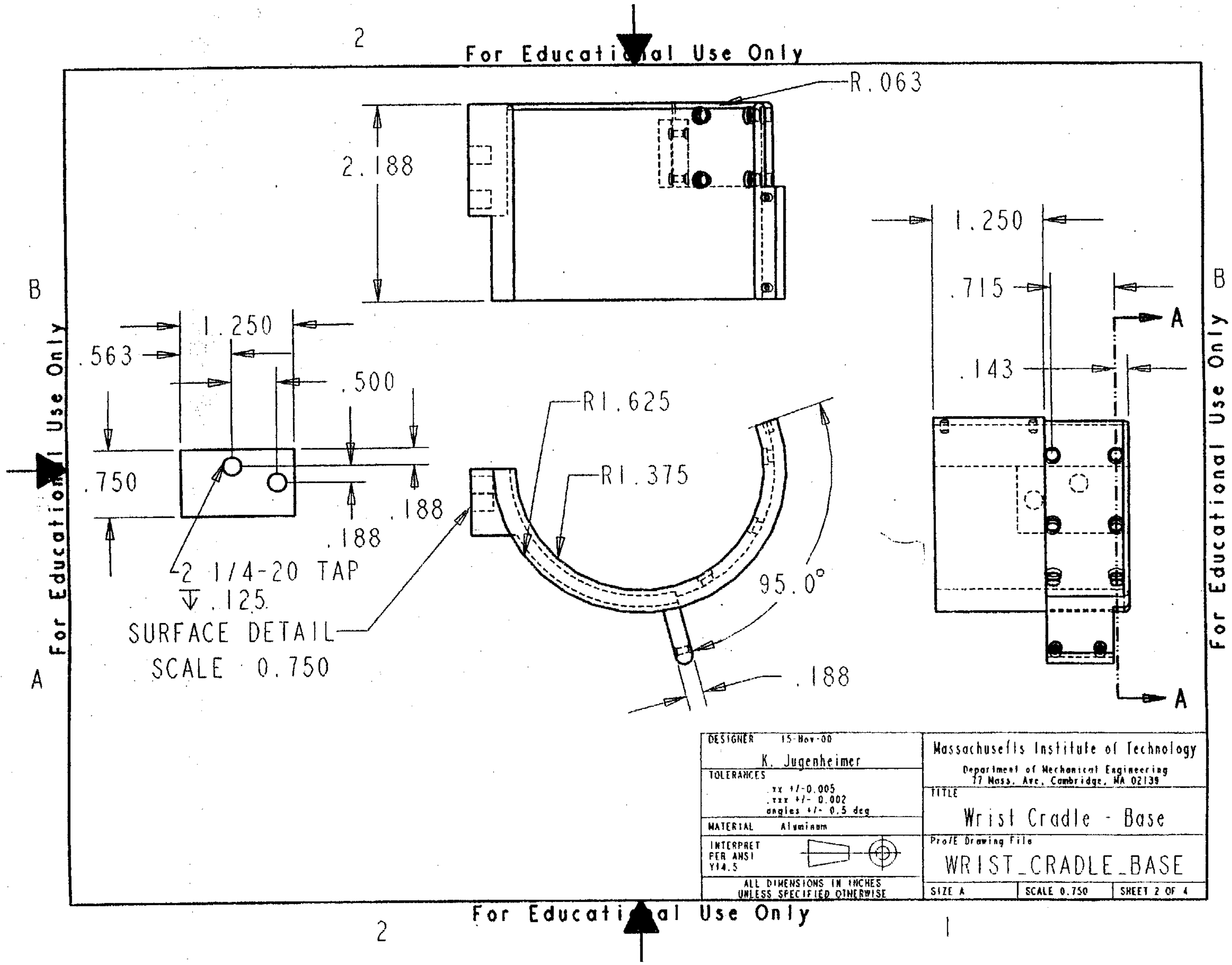
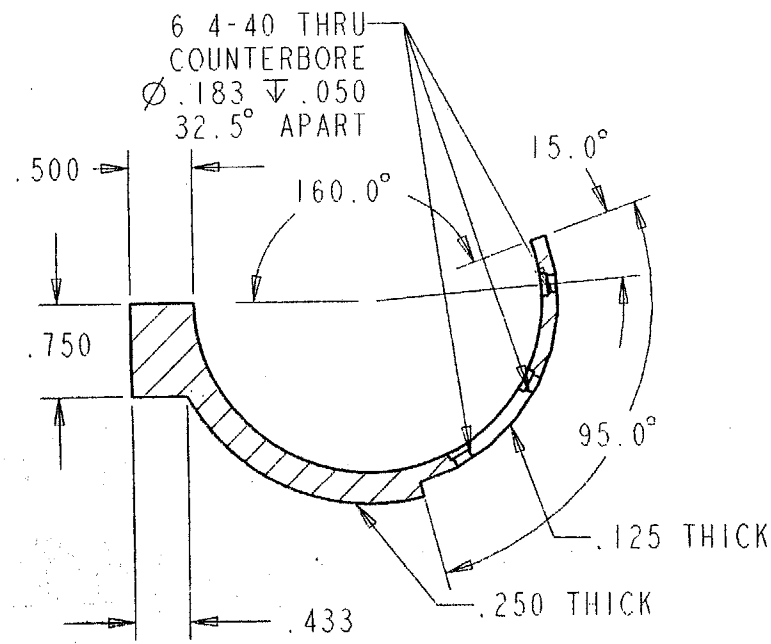
For Educational Use Only
For Educational Use Only

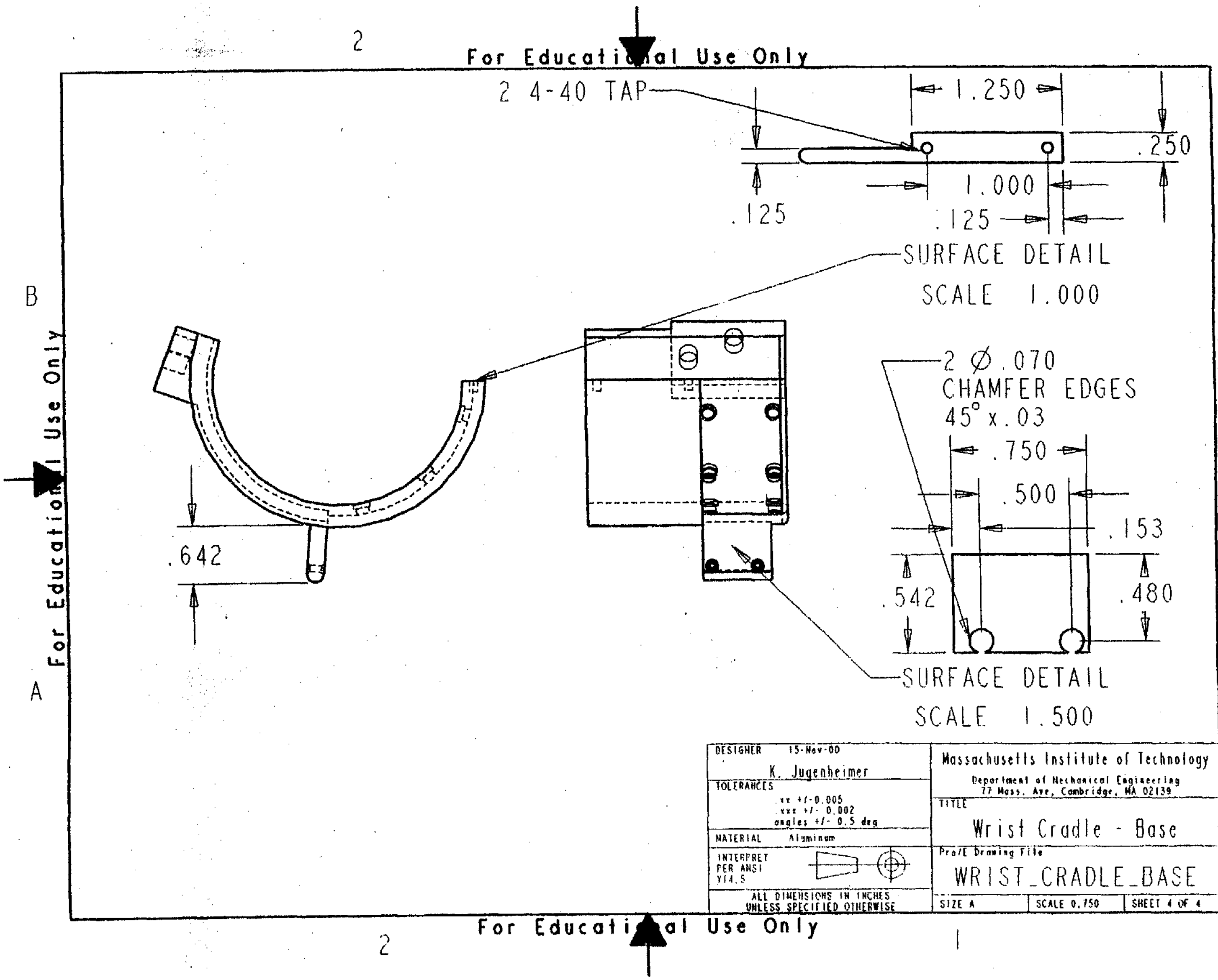

For Educational Use Only
R.063
2.188
1.250
.715
.143
A
B
1.250
.563
.500
.750
.188
.188
2 1/4-20 TAP
↧ .125
SURFACE DETAIL
SCALE 0.750
R1.625
R1.375
95.0°
.188
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Wrist Cradle - Base
Pro/E Drawing File
WRIST_CRADLE_BASE
SIZE A
SCALE 0.750
SHEET 2 OF 4



SECTION A-A
SCALE 0.875

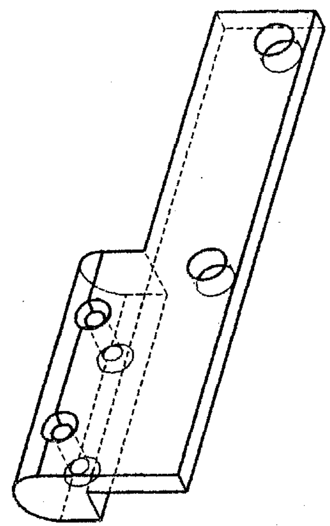
DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Wrist Cradle - Base
MATERIAL Aluminum	Pro/E Drawing File WRIST_CRADLE_BASE
INTERPRET PER ANSI Y14.5	
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 0.750 · SHEET 3 OF 4

For Educational Use Only


For Educational Use Only
2 4-40 TAP
1.250
.250
1.000
.125
.125
SURFACE DETAIL
SCALE 1.000
2 Ø.070
CHAMFER EDGES
45° x.03
.750
.500
.153
.542
.480
.642
SURFACE DETAIL
SCALE 1.500
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Wrist Cradle - Base
Pro/E Drawing File
WRIST_CRADLE_BASE
SIZE A
SCALE 0.750
SHEET 4 OF 4

2

B



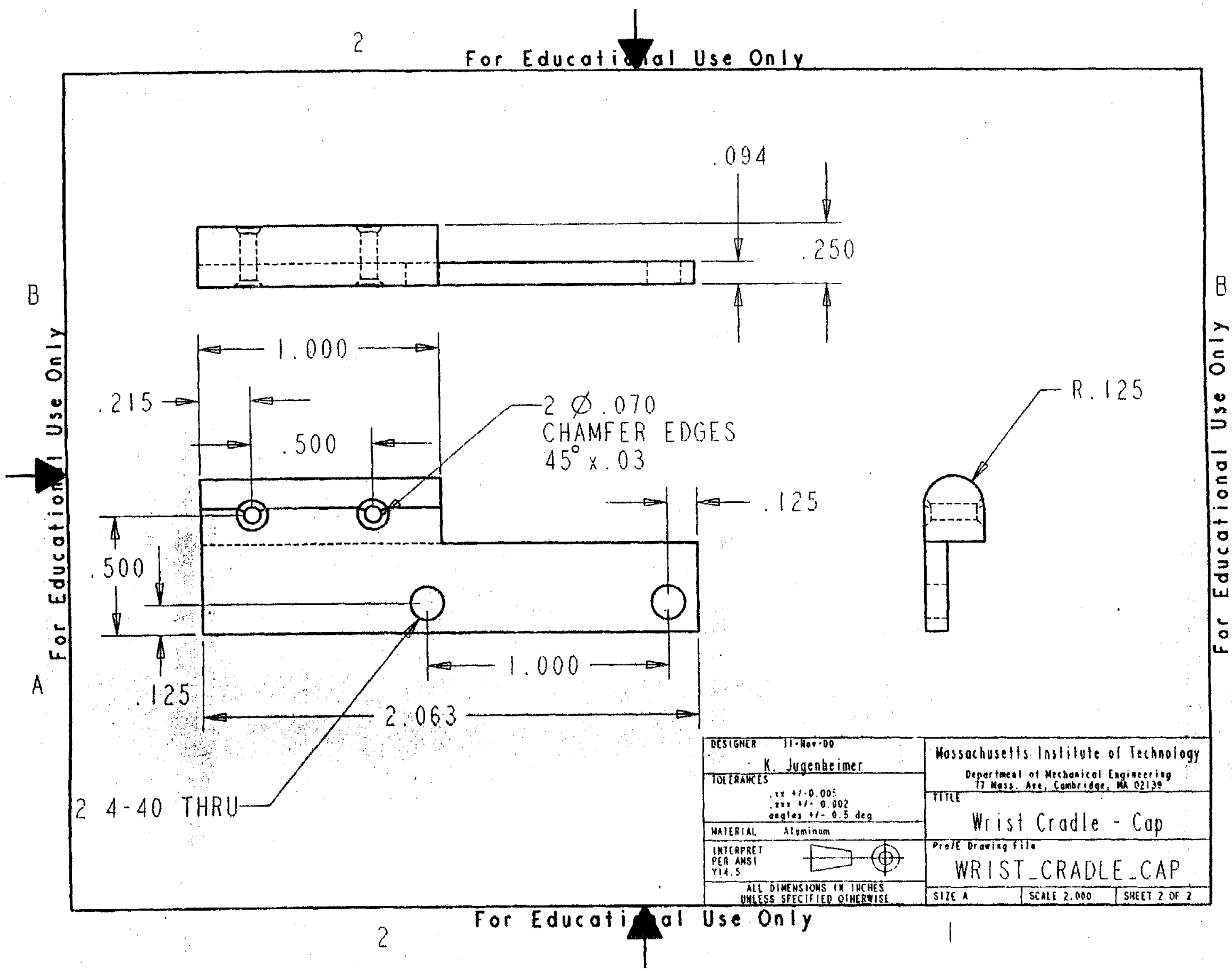
ISOMETRIC VIEW

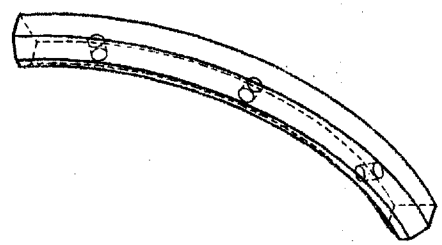
A

DESIGNER 11-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Wrist Cradle - Cap
MATERIAL Aluminum	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File WRIST_CRADLE_CAP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 2.000 | SHEET 1 OF 2

2 1

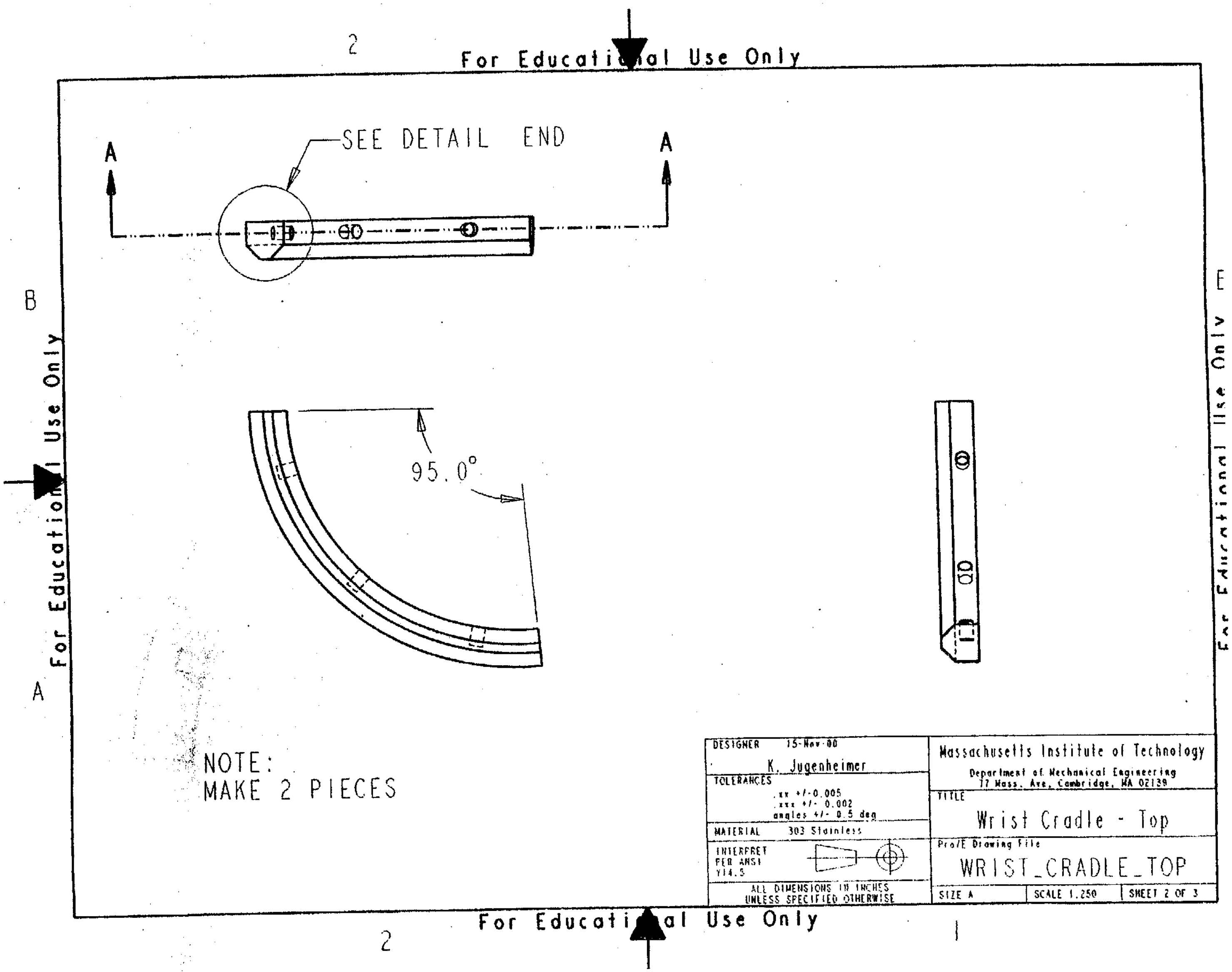
For Educational Use Only


For Educational Use Only
2
B
A
1
.094
.250
1.000
.215
.500
2 ∅.070
CHAMFER EDGES
45° x.03
.125
R.125
.500
.125
1.000
2.063
2 4-40 THRU
DESIGNER 11-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Wrist Cradle - Cap
Pro/E Drawing File
WRIST_CRADLE_CAP
SIZE A
SCALE 2.000
SHEET 2 OF 2

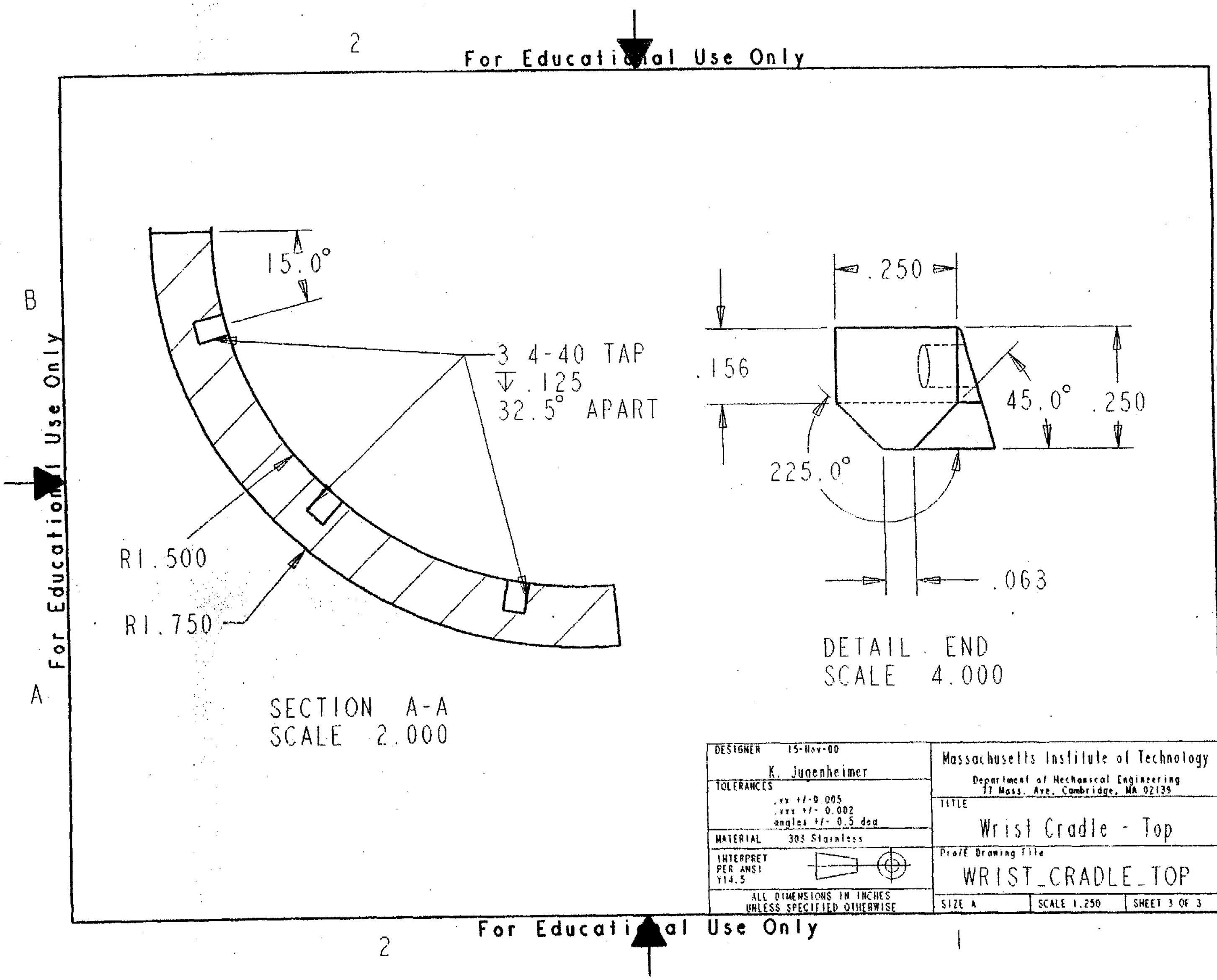


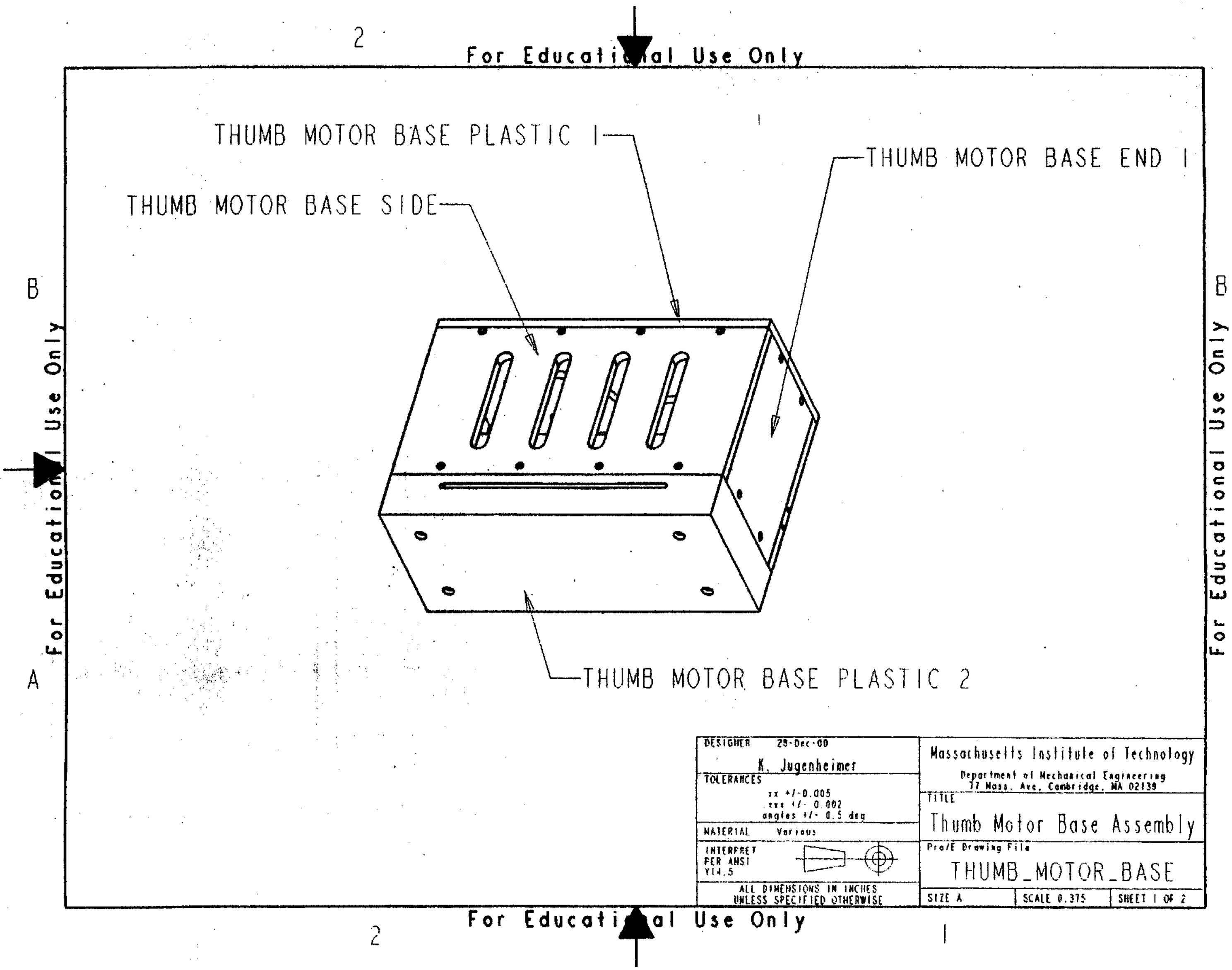
ISOMETRIC VIEW

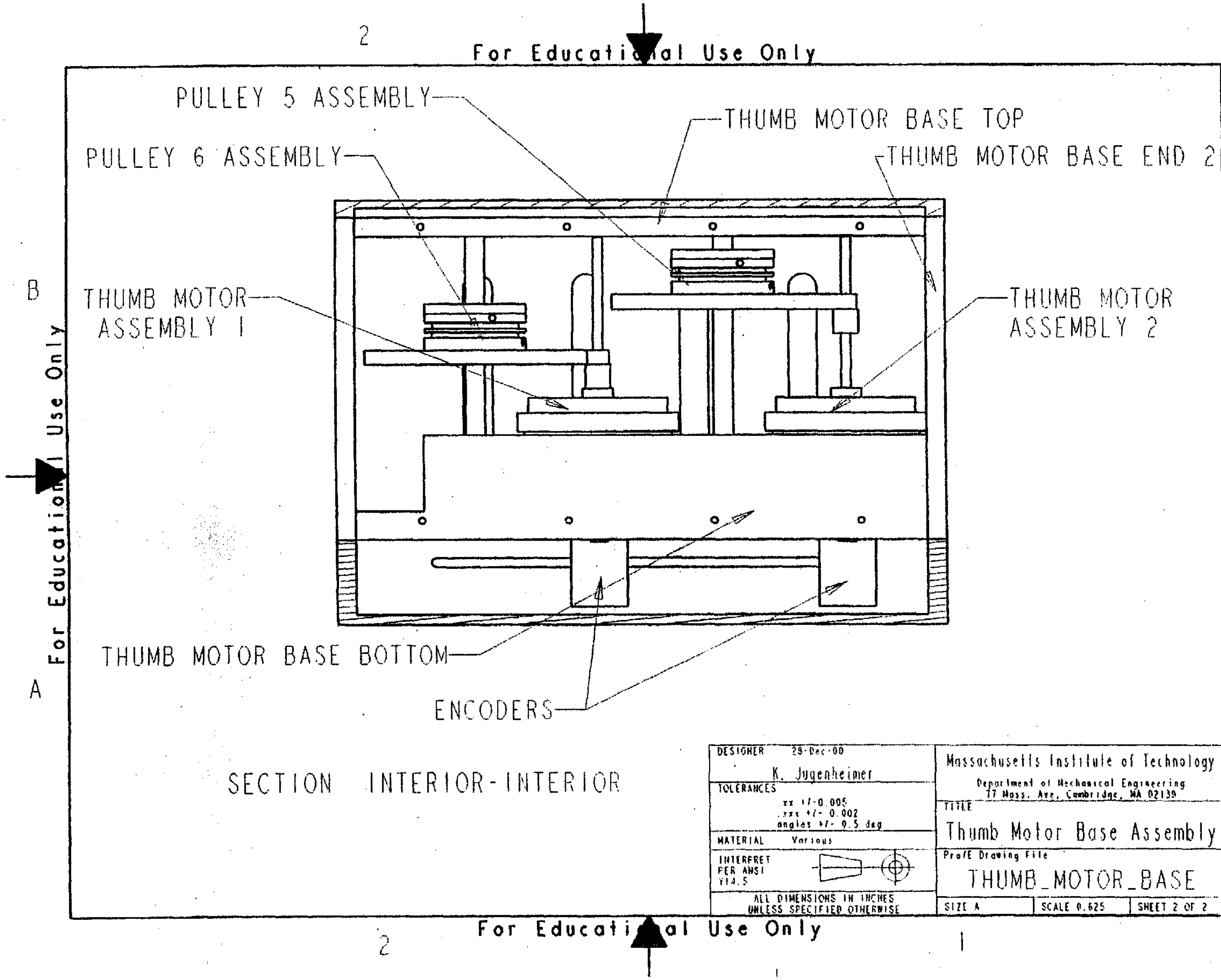
DESIGNER 15-Nov-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Wrist Cradle - Top
MATERIAL 303 Stainless	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File WRIST_CRADLE_TOP
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A	SCALE 1.250	SHEET 1 OF 3



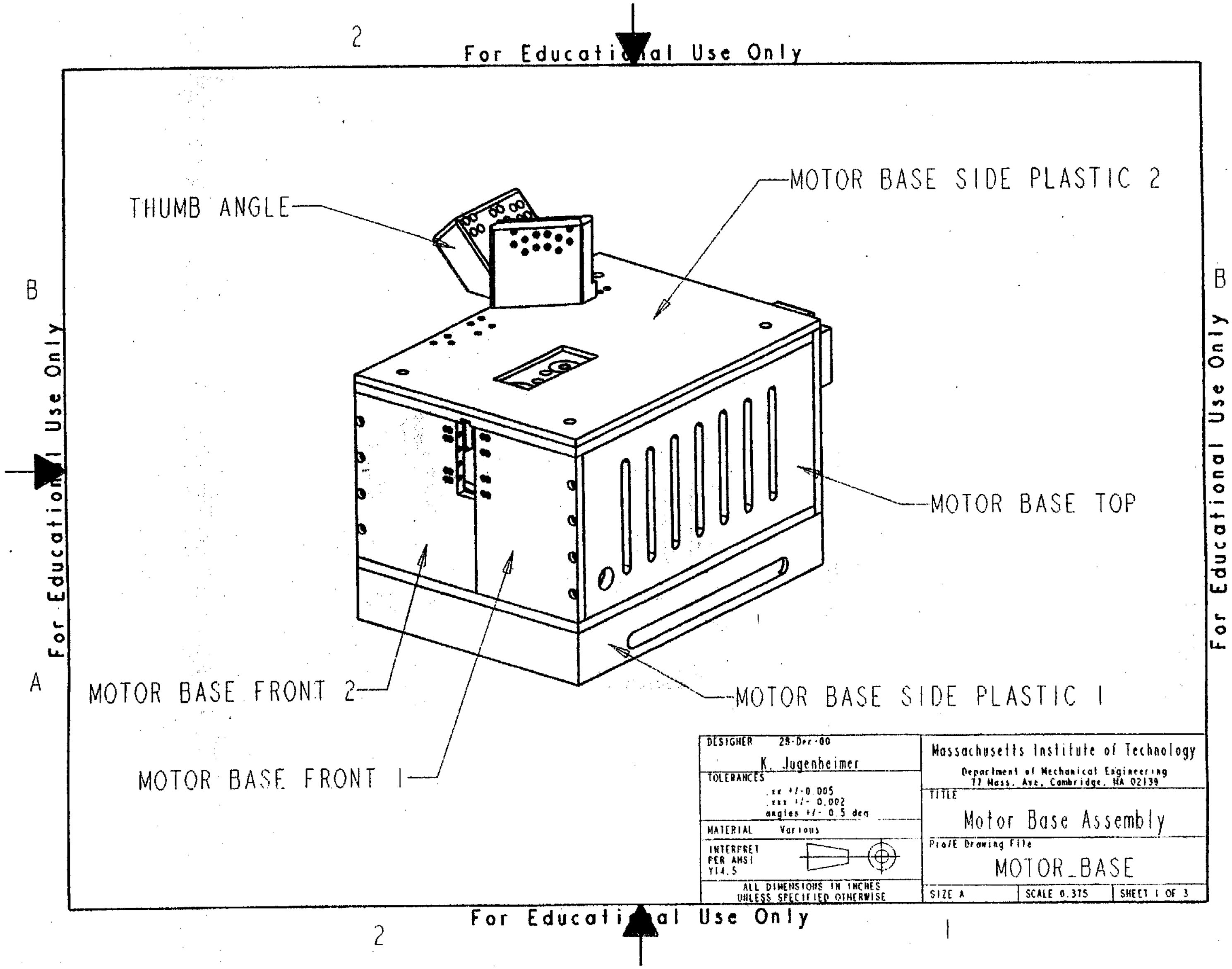
For Educational Use Only
2
A
A
SEE DETAIL END
B
A
E
95.0°
NOTE:
MAKE 2 PIECES
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL 303 Stainless
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Wrist Cradle - Top
Pro/E Drawing File
WRIST_CRADLE_TOP
SIZE A
SCALE 1.250
SHEET 2 OF 3


For Educational Use Only
2
B
A
15.0°
3 4-40 TAP
⊽ .125
32.5° APART
R1.500
R1.750
SECTION A-A
SCALE 2.000
.250
.156
45.0°
.250
225.0°
.063
DETAIL END
SCALE 4.000
DESIGNER 15-Nov-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL 303 Stainless
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Wrist Cradle - Top
Pro/E Drawing File
WRIST_CRADLE_TOP
SIZE A
SCALE 1.250
SHEET 3 OF 3
1

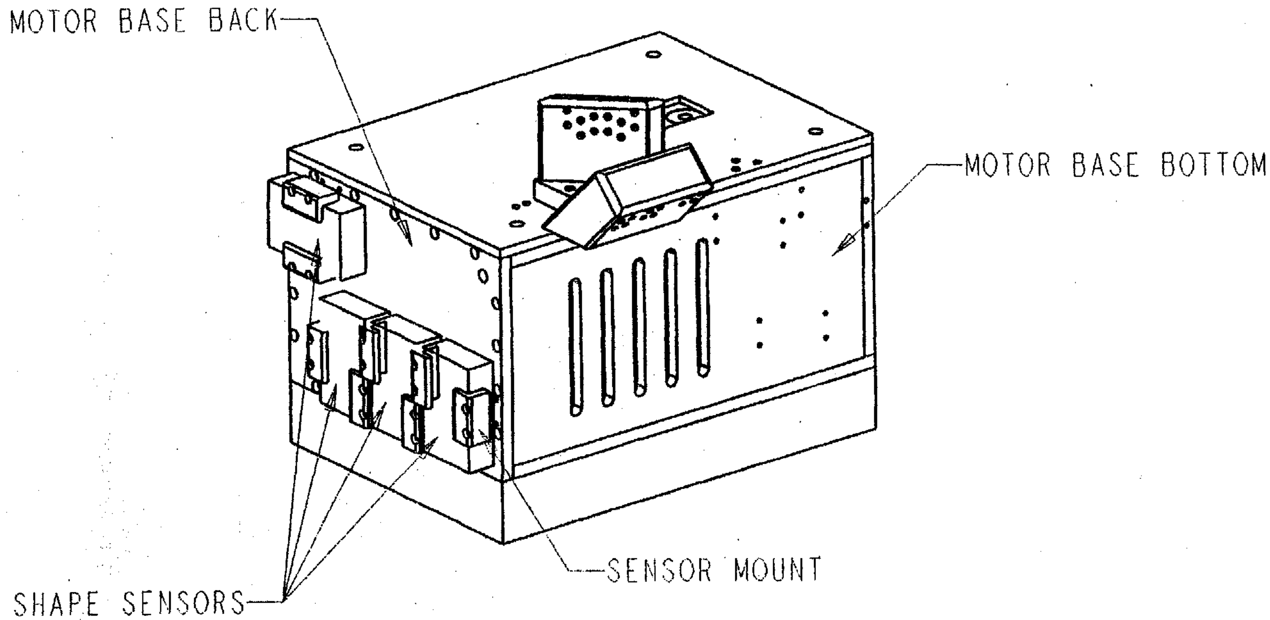

For Educational Use Only
THUMB MOTOR BASE PLASTIC 1
THUMB MOTOR BASE END 1
THUMB MOTOR BASE SIDE
THUMB MOTOR BASE PLASTIC 2
DESIGNER 29-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Various
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base Assembly
Pro/E Drawing File
THUMB_MOTOR_BASE
SIZE A
SCALE 0.375
SHEET 1 OF 2



For Educational Use Only
PULLEY 5 ASSEMBLY
THUMB MOTOR BASE TOP
PULLEY 6 ASSEMBLY
THUMB MOTOR BASE END 2
THUMB MOTOR ASSEMBLY 1
THUMB MOTOR ASSEMBLY 2
THUMB MOTOR BASE BOTTOM
ENCODERS
SECTION INTERIOR-INTERIOR
DESIGNER 29-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Various
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Thumb Motor Base Assembly
ProE Drawing File
THUMB_MOTOR_BASE
SIZE A
SCALE 0.625
SHEET 2 OF 2

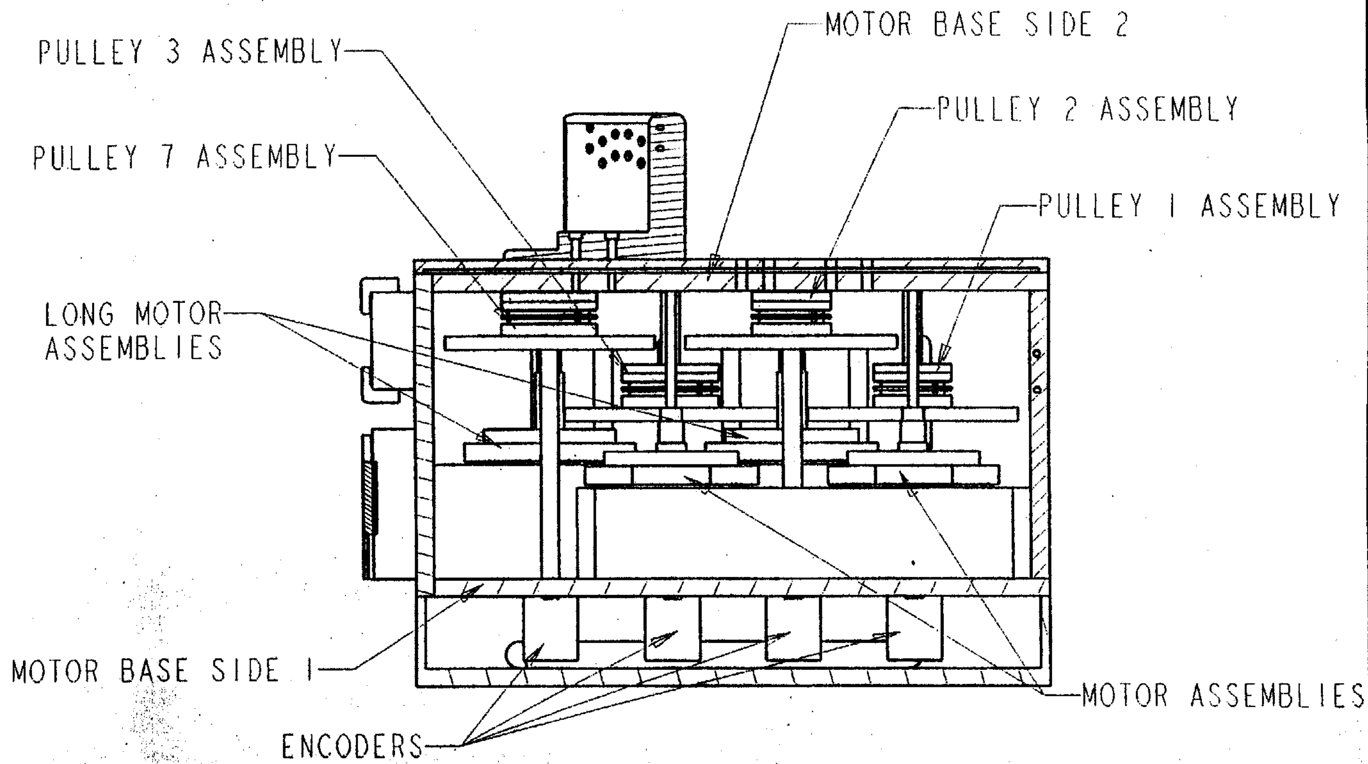


For Educational Use Only
THUMB ANGLE
MOTOR BASE SIDE PLASTIC 2
MOTOR BASE TOP
MOTOR BASE FRONT 2
MOTOR BASE FRONT 1
MOTOR BASE SIDE PLASTIC 1
DESIGNER 28-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Various
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Motor Base Assembly
Pro/E Drawing File
MOTOR_BASE
SIZE A
SCALE 0.375
SHEET 1 OF 3



DESIGNER 28-Dec-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base Assembly
MATERIAL Various	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_BASE
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A	SCALE 0.375	SHEET 2 OF 3

For Educational Use Only



SECTION INTERIOR-INTERIOR

DESIGNER 25-Dec-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Base Assembly
MATERIAL Various	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_BASE
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 0.500 · SHEET 3 OF 3

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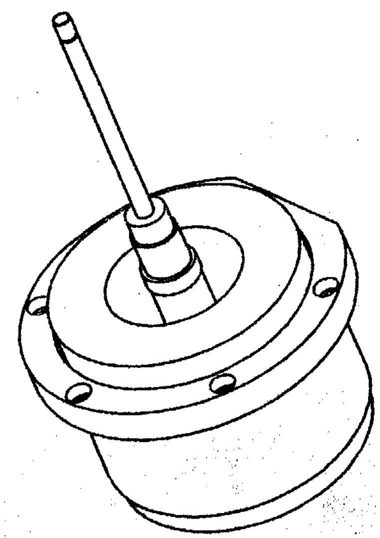
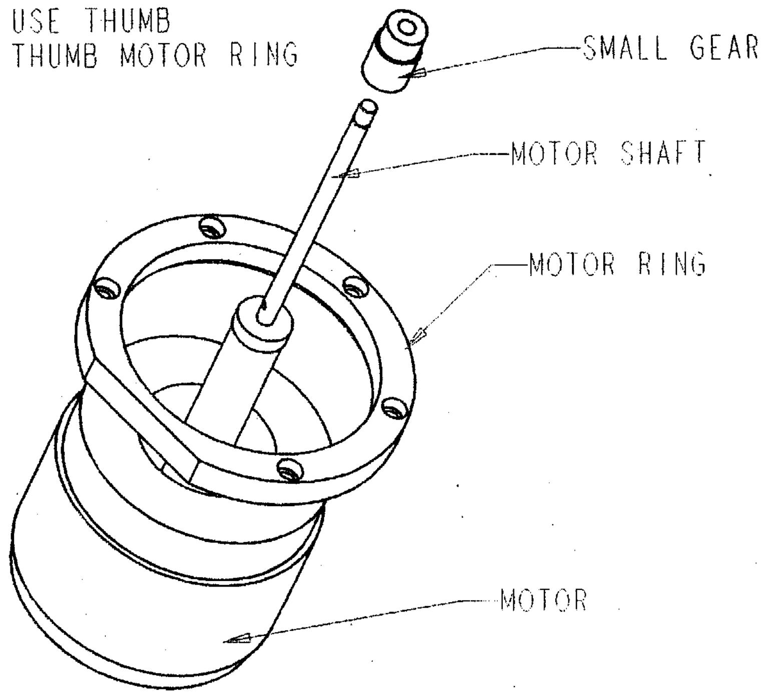


DESIGNER 29-Dec-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Assembly
MATERIAL Various	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_ASSEMBLY
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 1.000 · SHEET 1 OF 2

MOTOR ASSEMBLIES USE MOTOR SHAFT
LONG MOTOR ASSEMBLIES USE LONG MOTOR SHAFT
THUMB MOTOR ASSEMBLIES USE THUMB
MOTOR SHAFTS 1 & 2 AND THUMB MOTOR RING

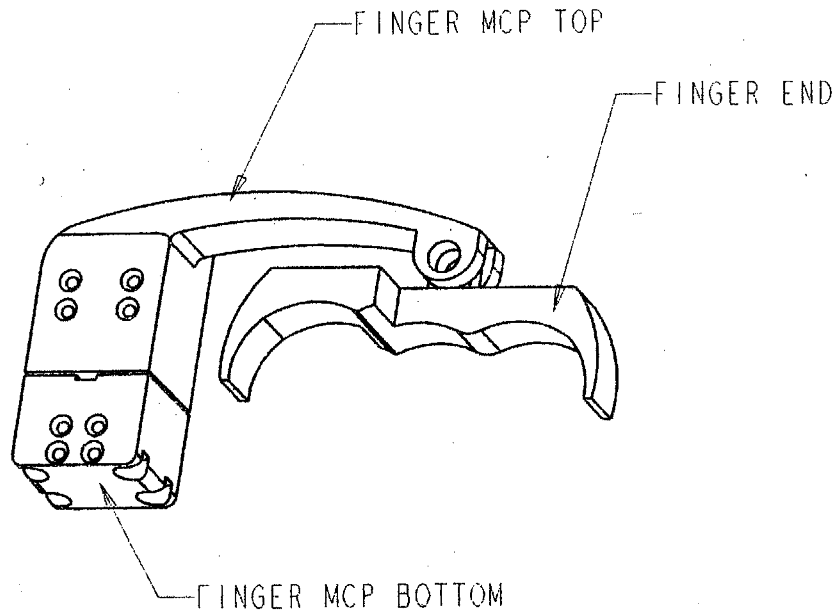


DESIGNER 28-Dec-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Motor Assembly
MATERIAL Various	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File MOTOR_ASSEMBLY
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A SCALE 1.000 SHEET 2 OF 2

For Educational Use Only

2

B



B

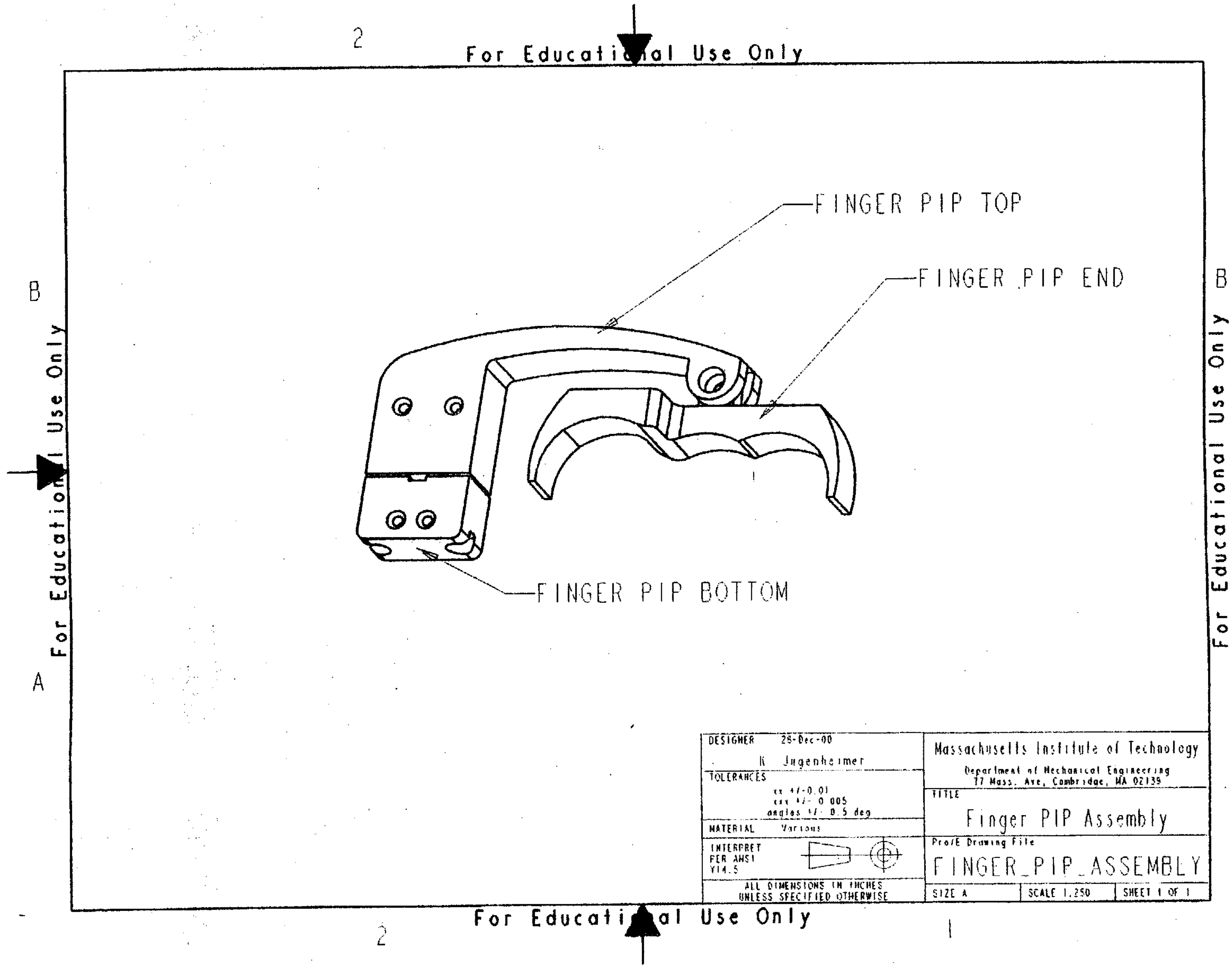
A

DESIGNER 28-Dec-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/- 0.01 .xxx +/- 0.005 angles +/- 0.5 deg	TITLE Finger MCP Assembly
MATERIAL Various	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File FINGER_MCP_ASSEMBLY
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 1.250 / SHEET 1 OF 1

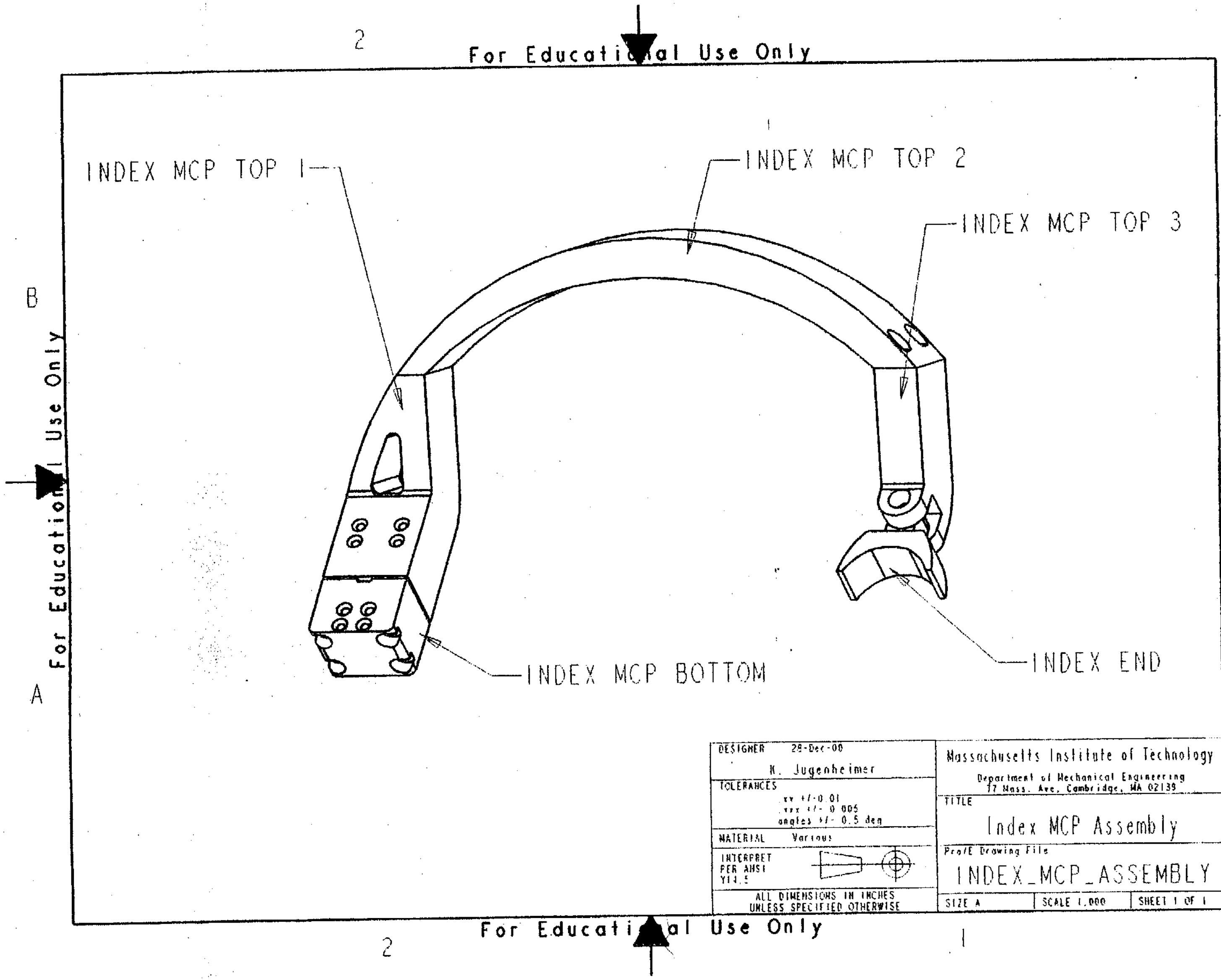
2

1

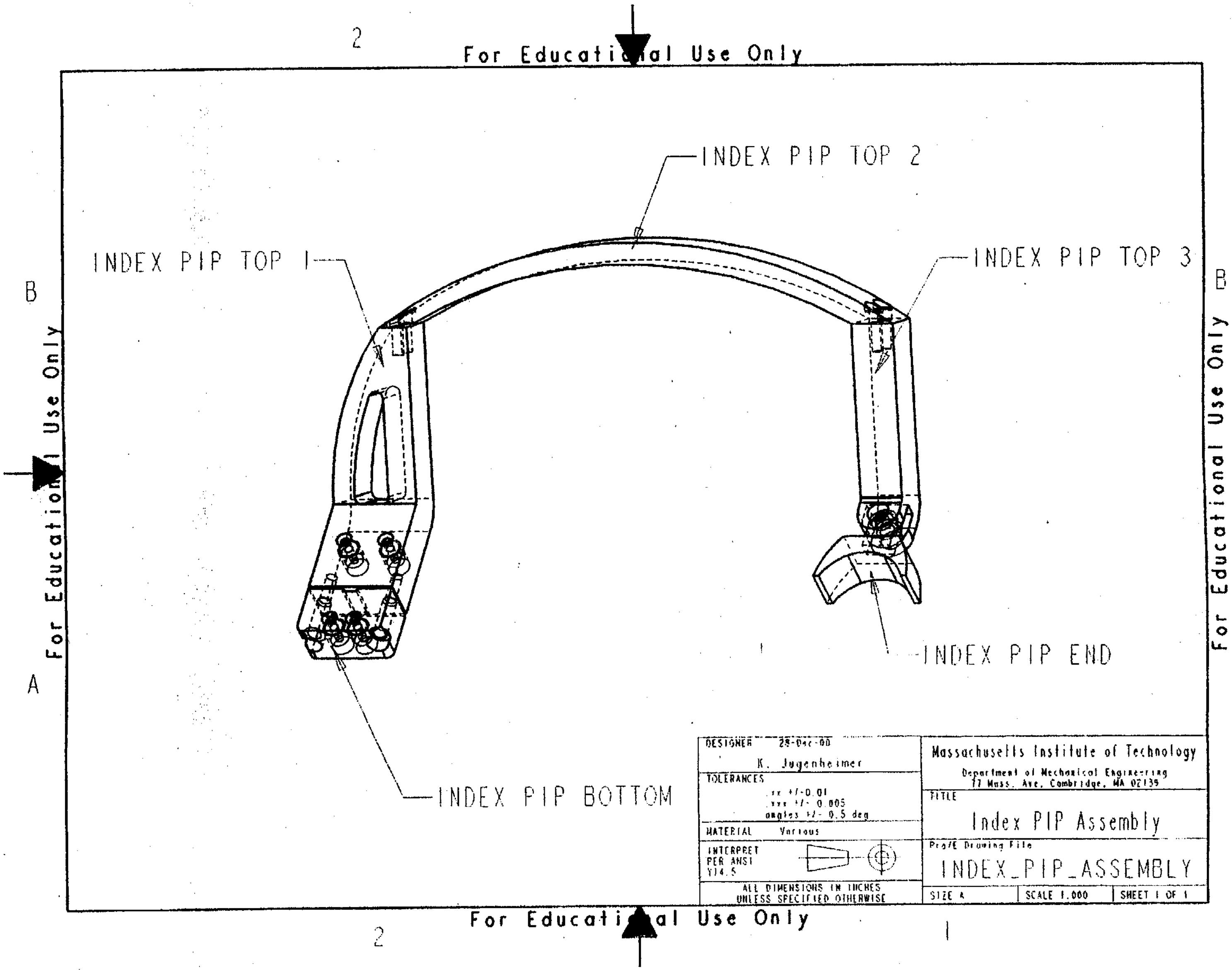
For Educational Use Only



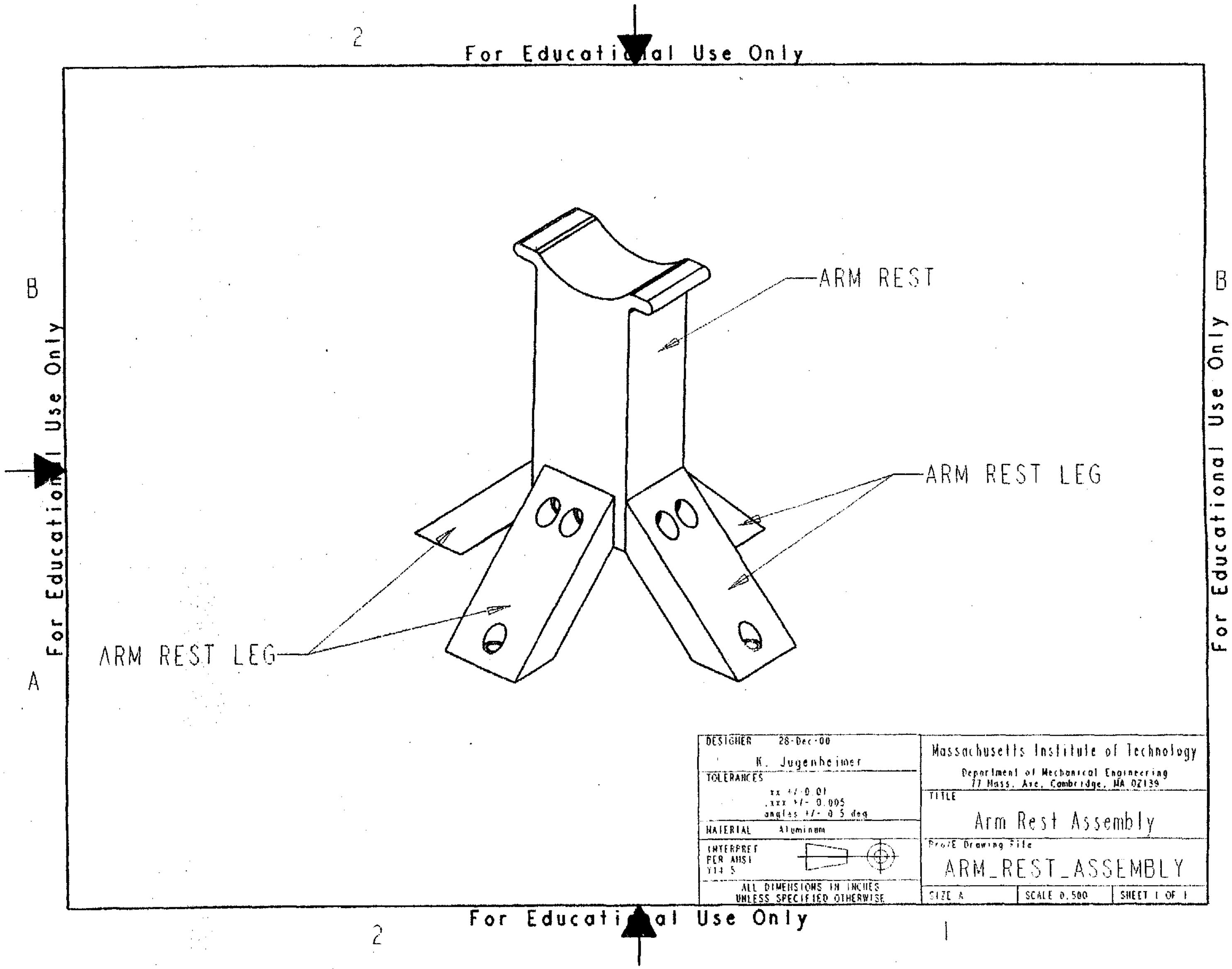
For Educational Use Only
2
B
A
FINGER PIP TOP
FINGER PIP END
FINGER PIP BOTTOM
DESIGNER 28-Dec-00
K Jugenheimer
TOLERANCES
xx +/-0.01
xxx +/- 0.005
angles +/- 0.5 deg
MATERIAL Various
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Finger PIP Assembly
Pro/E Drawing File
FINGER_PIP_ASSEMBLY
SIZE A
SCALE 1.250
SHEET 1 OF 1
1

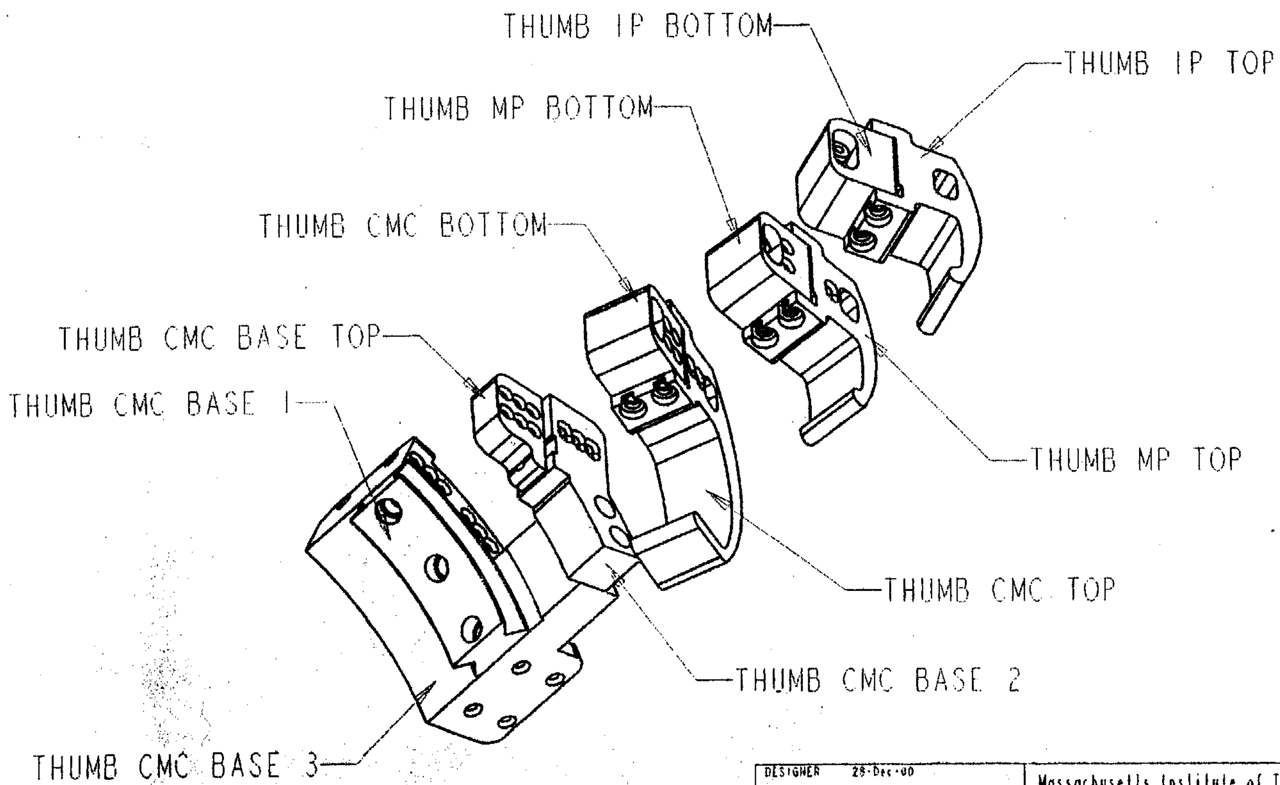


For Educational Use Only
INDEX MCP TOP 1
INDEX MCP TOP 2
INDEX MCP TOP 3
INDEX MCP BOTTOM
INDEX END
DESIGNER 29-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/-0.01
.xxx +/- 0.005
angles +/- 0.5 deg
MATERIAL Various
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Index MCP Assembly
Pro/E Drawing File
INDEX_MCP_ASSEMBLY
SIZE A
SCALE 1.000
SHEET 1 OF 1



For Educational Use Only
INDEX PIP TOP 2
INDEX PIP TOP 1
INDEX PIP TOP 3
INDEX PIP END
INDEX PIP BOTTOM
DESIGNER 28-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/-0.01
.xxx +/- 0.005
angles +/- 0.5 deg
MATERIAL Various
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Index PIP Assembly
Pro/E Drawing File
INDEX_PIP_ASSEMBLY
SIZE A
SCALE 1.000
SHEET 1 OF 1


For Educational Use Only
2
B
A
ARM REST
ARM REST LEG
ARM REST LEG
DESIGNER 28-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.01
.xxx +/- 0.005
angles +/- 0.5 deg
MATERIAL Aluminum
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Arm Rest Assembly
Pro/E Drawing File
ARM_REST_ASSEMBLY
SIZE A
SCALE 0.500
SHEET 1 OF 1
1



CMC BASE, CMC, MP AND IP CONNECTED
WITH THUMB FLEXURES

DESIGNER 28-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/-0.01
.xxx +/- 0.005
angles +/- 0.5 deg
MATERIAL Various
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE

Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139

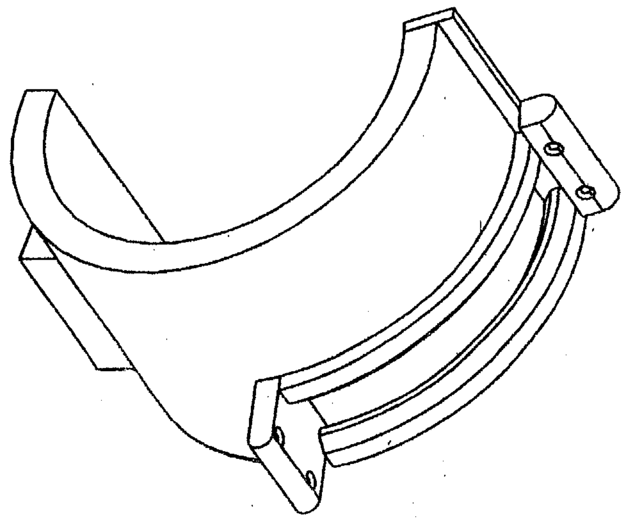
TITLE
Thumb Assembly

Pro/E Drawing File
THUMB_ASSEMBLY

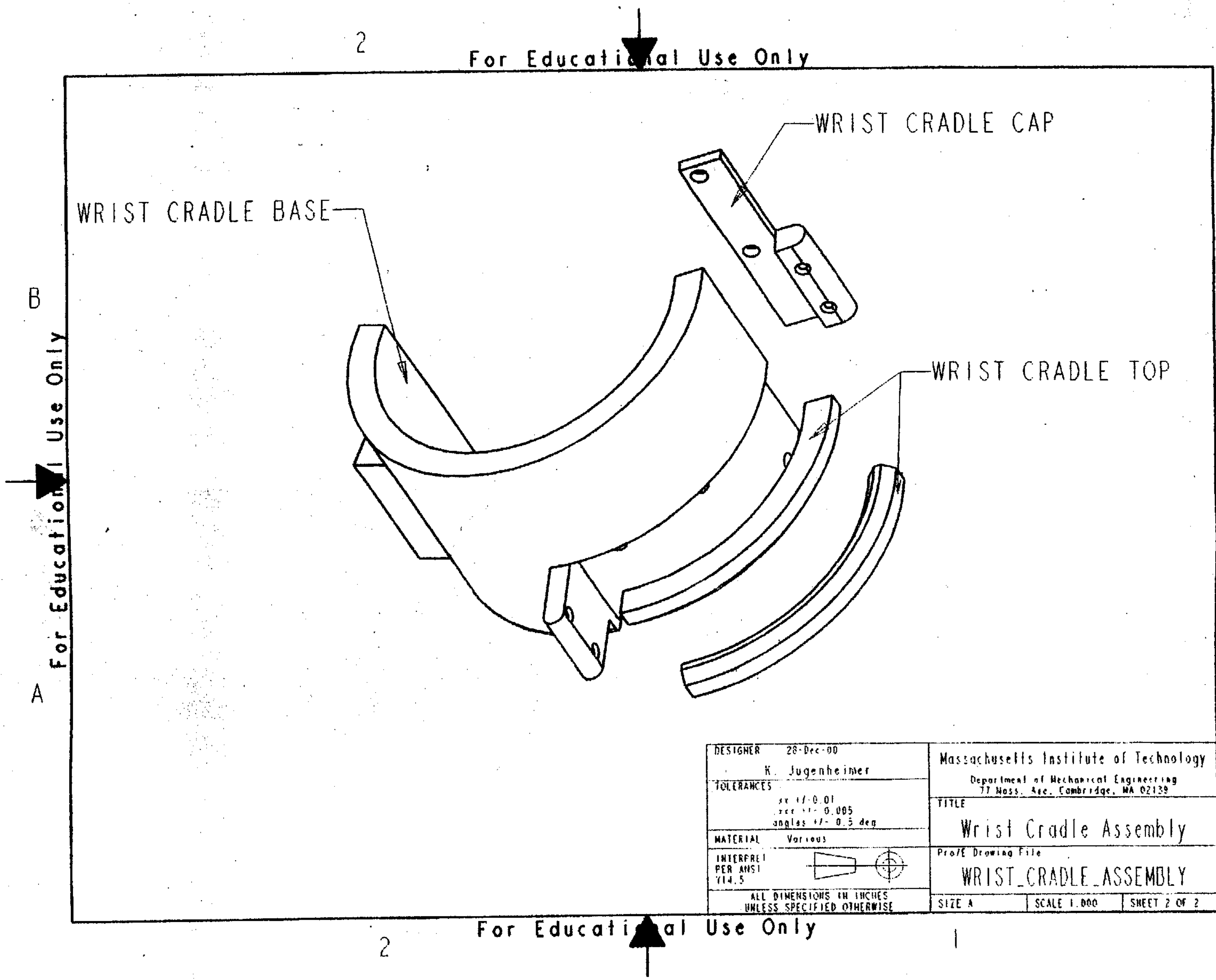
SIZE A | SCALE 1.000 | SHEET 1 OF 1

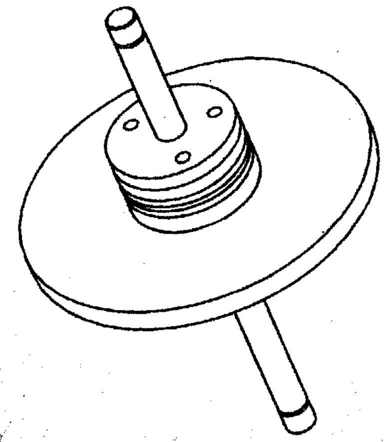
For Educational Use Only

For Educational Use Only



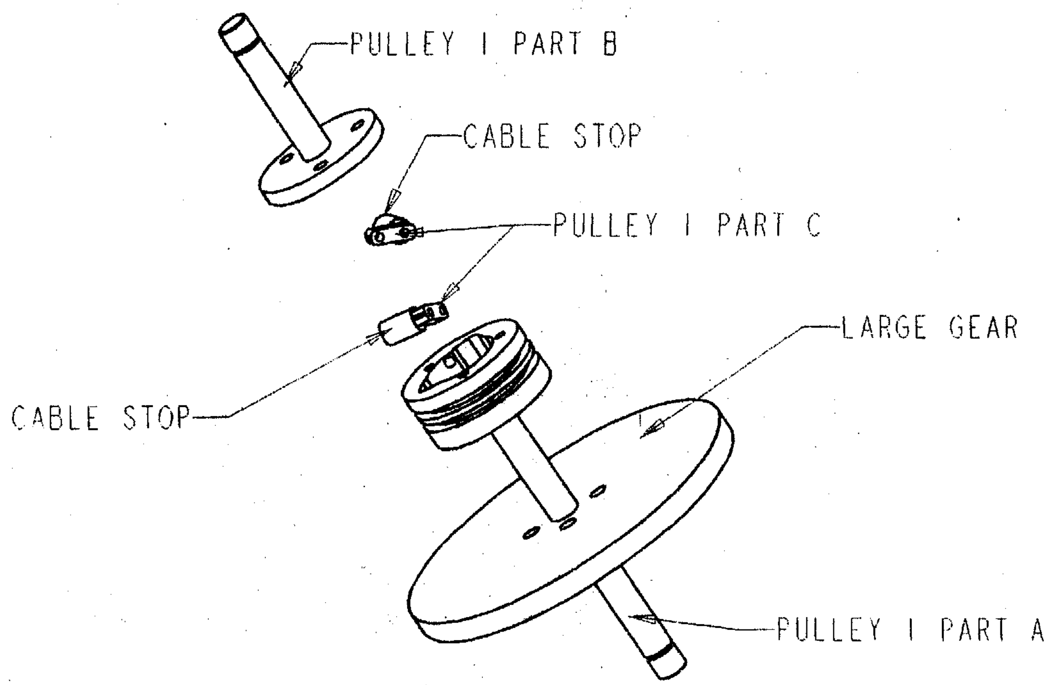
DESIGNER 28-Dec-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.01 .xxx +/- 0.005 angles +/- 0.5 deg	TITLE Wrist Cradle Assembly
MATERIAL Various	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File WRIST_CRADLE_ASSEMBLY
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A | SCALE 1.000 | SHEET 1 OF 2


2
B
A
WRIST CRADLE CAP
WRIST CRADLE BASE
WRIST CRADLE TOP
DESIGNER 28-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/- 0.01
.xxx +/- 0.005
angles +/- 0.5 deg
MATERIAL Various
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave. Cambridge, MA 02139
TITLE
Wrist Cradle Assembly
Pro/E Drawing File
WRIST_CRADLE_ASSEMBLY
SIZE A
SCALE 1.000
SHEET 2 OF 2
1



DESIGNER 29-Dec-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave, Cambridge, MA 02139
TOLERANCES .xx +/-0.01 .xxx +/- 0.005 angles +/- 0.5 deg	TITLE Pulley I Assembly
MATERIAL Various	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_I_ASSEMBLY
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A / SCALE 0.875 / SHEET 1 OF 2

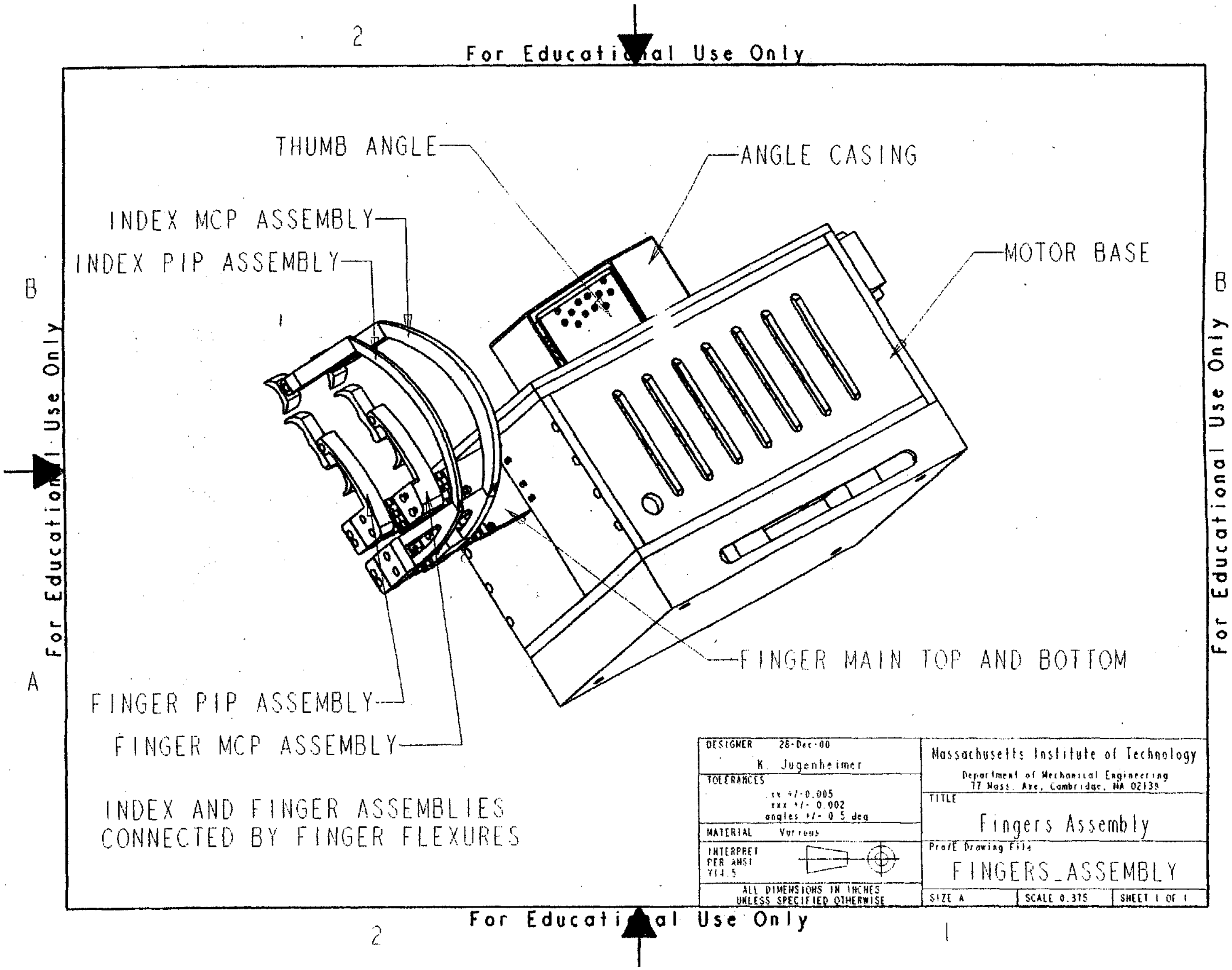
For Educational Use Only



OTHER PULLEY ASSEMBLIES ARE THE SAME
ALL USE RESPECTIVE PARTS A & B
PULLEYS 1, 2 & 5 USE PULLEY 1 PART C
PULLEYS 3, 6 & 7 USE PULLEY 3 PART C

DESIGNER 28-Dec-00 K. Jugenheimer	Massachusetts Institute of Technology Department of Mechanical Engineering 77 Mass. Ave. Cambridge, MA 02139
TOLERANCES .xx +/-0.005 .xxx +/- 0.002 angles +/- 0.5 deg	TITLE Pulley 1 Assembly
MATERIAL Various	
INTERPRET PER ANSI Y14.5	Pro/E Drawing File PULLEY_1_ASSEMBLY
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE	SIZE A · SCALE 0.875 · SHEET 2 OF 2

For Educational Use Only



For Educational Use Only
THUMB ANGLE
ANGLE CASING
INDEX MCP ASSEMBLY
INDEX PIP ASSEMBLY
MOTOR BASE
FINGER MAIN TOP AND BOTTOM
FINGER PIP ASSEMBLY
FINGER MCP ASSEMBLY
INDEX AND FINGER ASSEMBLIES CONNECTED BY FINGER FLEXURES
DESIGNER 28-Dec-00
K. Jugenheimer
TOLERANCES
.xx +/-0.005
.xxx +/- 0.002
angles +/- 0.5 deg
MATERIAL Various
INTERPRET PER ANSI Y14.5
ALL DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE
Massachusetts Institute of Technology
Department of Mechanical Engineering
77 Mass. Ave, Cambridge, MA 02139
TITLE
Fingers Assembly
Pro/E Drawing File
FINGERS_ASSEMBLY
SIZE A
SCALE 0.375
SHEET 1 OF 1

Bibliography

[1] Keith M. Adams and Sandra T. Thompson. Continuous passive motion use in hand therapy. *Hand Clinics*, 12(1):109–27, February 1996.

[2] J.D. Arbuckle and D.A. McGrouther. Measurement of the arc of digital flexion and joint movement ranges. *The Journal of Hand Surgery (British)*, 20B(6):836–40, December 1995.

[3] M.F. Ashby. *Materials Selection in Mechanical Design.* Butterworth-Heinemann, Boston, 1996.

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[6] R. Chase. *Anatomy of the Thumb*, chapter 2, pages 15–30. Churchill Livingstone, New York, 1994.

[7] DiaCom Corporation. http://www.diacom.com.

[8] Diane Dirette and Jim Hinojosa. Effects of continuous passive motion on the edematous hands of two persons with flaccid hemiplegia. *American Journal of Occupational Therapy*, 48(5):403–409, 1994.

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