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The Human Airpuck

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(MAYNARD)

Have you ever wanted to have your students experience what life would be like in a frictionless frame of reference? Would Newton's laws of motion and gravity be more apparent if friction weren't around to hide their effects?

During the summer of 1987, I was fortunate to take part in a course for physics teachers at the Virginia Military Institute. During this course, Barbara Saur (from Kentwood High School in Kent, Washington) described how to make an aircart upon which a person could sit. It proved to be a very simple device to build and an extremely useful demonstration tool for several different topics.

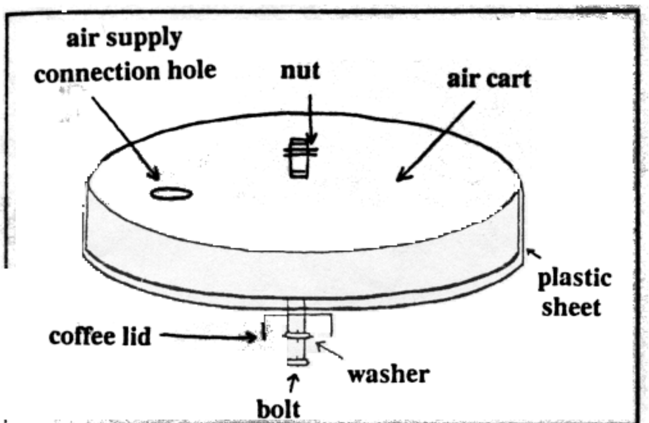

Fig. 1. Design of the airpuck.

Materials required to build this cart are:

- a wooden board (0.5- to 1.0-in thick) that can be shaped into a disk 3.0 ft in diameter
- a plastic coffee-can lid
- a (1.0- to 1.5-in long) bolt, washer, and nut
- a 12.5-sq-ft sheet of plastic at least 4-mil thick
- a staple gun with large staples
- a bicycle tire
- hammer and nails to be used to attach the tire to the wooden wheel, and
- an air supply

Cut the board into a 3-ft circle with a hole in its center that is just large enough for the bolt to slip through. The rim of the wheel should be sanded into rounded edges. In addition, a hole should be drilled into the wheel about 10 (15) in from the center. This hole should be slightly larger than the diameter of the nozzle end of the air-supply hose.

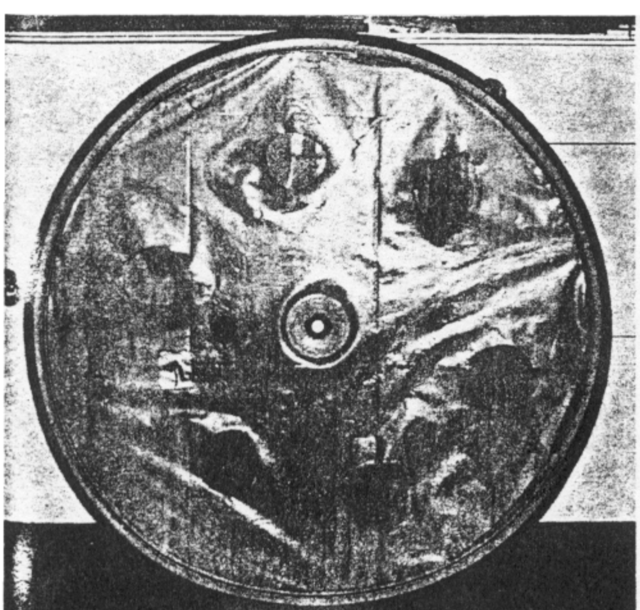

Fig. 2. Underside of the airpuck.

SCALE = 1" = 1'

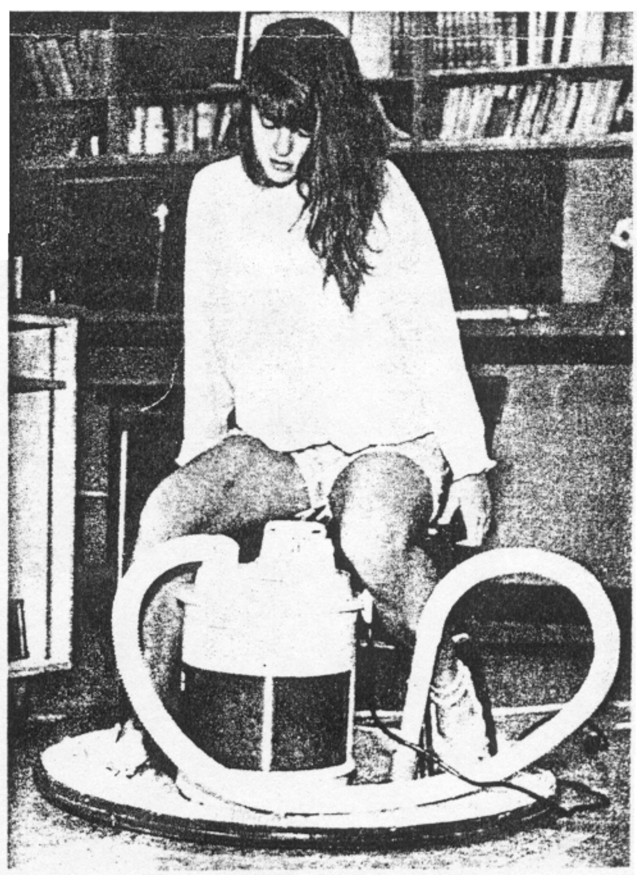

Fig. 3. A student moves across the room on the airpuck.

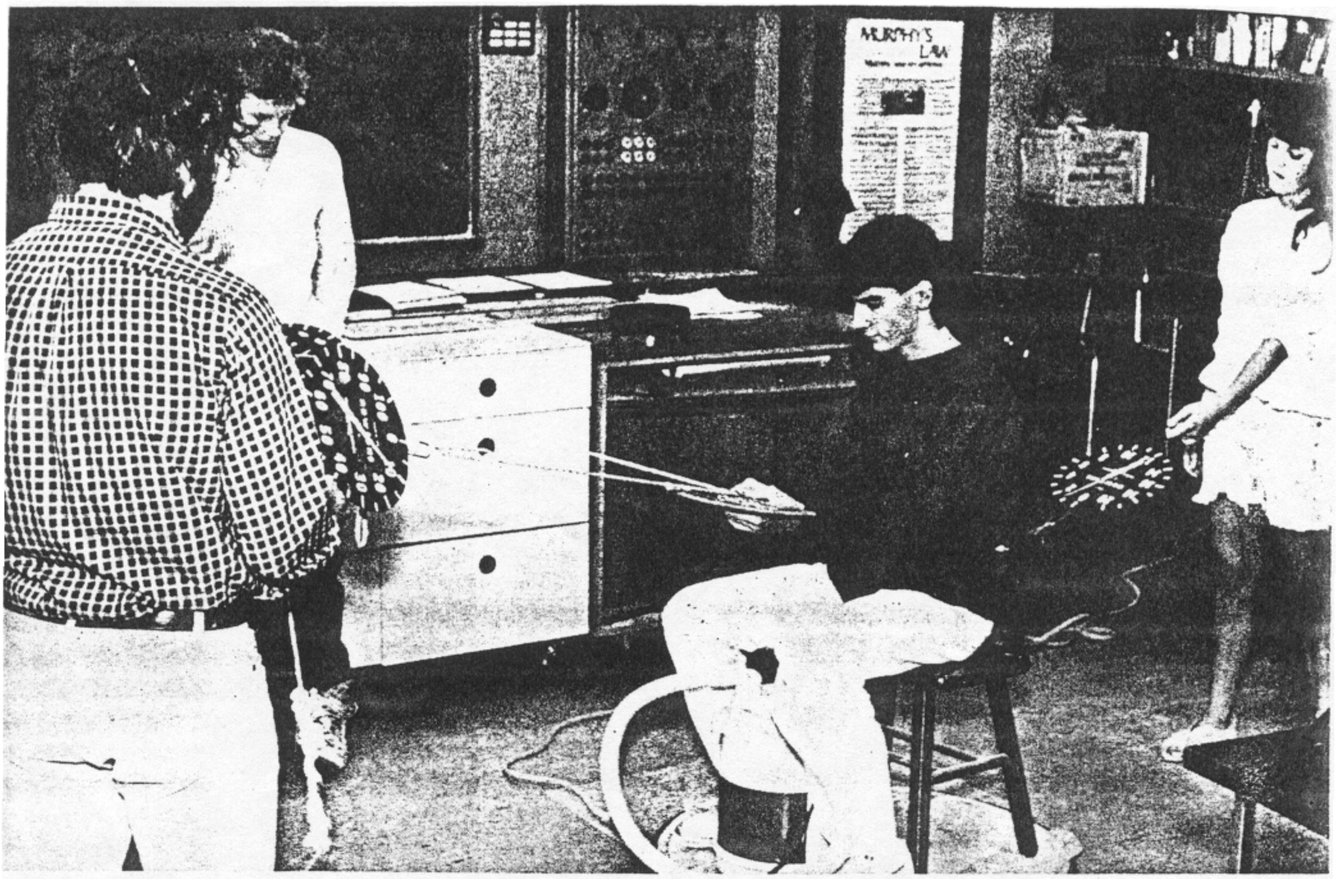

Fig. 4. Resolving vectors. (Photos courtesy of Joseph Damplo.)

Now stretch the sheet of plastic tightly across the bottom of the wooden disk and staple it to the top of the disk along the wheel's rim. Put a hole in the center of the coffee-can lid big enough for the bolt to slide through. This lid is going to function as an extended washer for the bolt as it goes through the plastic. Now put the bolt through the washer, the lid, plastic sheet, and wooden disk. Screw the nut tightly to the bolt on the top of the aircart, as shown in Figs. 1 and 2.

Cut six holes in the plastic at a radial distance of about 15 in from the center of the wheel and evenly spaced around the circumference of the wheel. Each of these holes should have a diameter of about 5- to 6-in. Be sure that none of these holes is in direct alignment with the air supply hole.

Cut the bicycle tire and wrap it around the rim of the wooden wheel, nailing it to the wheel on the top side. This will act as a bumper for the wheel so that the plastic along the edge of the wheel won't rip when the aircart hits other objects.

Finally, put the air pump on the cart with the hose nozzle stuck into the hole in the wheel. If the nozzle has a loose fit, use duct tape to hold it in place. You can also place a chair on the disk to make it easier for the operator to maintain his or her balance.

This aircart has proven to be a most useful tool for a large series of demonstrations. For instance, we have used it to demonstrate that a body in motion remains in motion when not acted upon by an outside force. To show this, a student is told to maintain her balance while she rides the cart across the floor, making sure the tire does not come into contact with the floor. It quickly becomes obvious that a rider has little control over the cart's motion (Fig. 3).

When we talk about vector addition using forces applied to an object along nonparallel lines, we consider the problem generated by having two students pull in known directions with known forces on the aircart. Then we mathematically solve for what equilibrant is required to balance these forces. Once we have mathematically solved this problem, the students test their theory. To do this, force scales are tied to the ends of a rope. These scales are pulled on by two class members. The student on the cart holds the center of this rope against a giant protractor. He can thus assure that the students pull on him at the angles described in the original problem. A third student now pulls on a third scale that has been tied to the back of the chair on the cart. When the cart is returned to a state of equilibrium, we see if the third student is applying a force equal in magnitude and direction to that predicted during our calculation (Fig. 4).

Finally, when we study Newton's third law, students on two carts play catch with a medicine ball (Fig. 5). The class is able to see the student's response both when throwing and catching the ball. In this way, they can see how the ball

Fig. 5. Students demonstrating Newton's third law.

"pushes" one student backward when the other student throws it forward. One problem with which you may have to deal is that during the throwing and catching students may lean so that the tire comes in contact with the floor. Be careful to remind them to maintain their balance throughout this demonstration.

These are only a few ideas for the use of the aircart. It is a popular device that permits us to demonstrate topics usually relegated to airtrack experiments. This is a much less expensive piece of equipment than the airtrack. In addition, owing to the personalized nature of these demonstrations, the students feel more a part of the process. This is especially true for the student riding on the cart. For this reason, we try to repeat each experiment with different students riding the cart so that many students get a firsthand experience with the law of physics being studied.

Significantly, and in contrast to airtracks, this airpuck device can easily be built in the typical high school industrial arts room by students. In this way, the students also gain experience in designing and/or building equipment to be used in class.

Oh, one last point. We have found that our carts can support weights of up to 220 lbs easily and, during the demonstration at VMI, people much heavier than that were able to coast around the room on a cart. So, if you want to take a firsthand role in the demonstration, go ahead and have fun. ♦

Personal hovercraft with accessories

AAPT Apparatus Competition 1998 August 3

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INTRODUCTION

Hovercraft are vehicles that are supported by a cushion of compressed air or other gasses. Typically a fan or turbine is used to force air under the vehicle and some sort of skirt around the bottom perimeter of the vehicle serves to hold the air there. Since hovercraft are lifted by a cushion of air, they experience very little friction with the surface under them and can move easily over water as well as land. Commercial hovercraft range in size from the huge craft that are used to carry both passengers and cars across the English Channel (25 British pounds for a person, one way, 35 minutes Dover to Calais) to single person inflatable hovercraft built for pleasure use. Through the internet many kits are available for building your own hovercraft and there are hovercraft clubs in many parts of the world devoted to designing hovercraft, building hovercraft, or racing hovercraft.[1] A major deterrent to the general use of hovercraft in our transportation system is the difficulty in controlling their motion. However, it is precisely this difficulty that makes a hovercraft such a useful tool in a physics classroom.

Hovercraft have been used by teachers of physics for many years, though there are few references to their construction or use in the literature. An article in the November 1989 issue of The Physics Teacher by Ken Altshuler, "The Human Airpuck", describes how to make a basic person sized hovercraft out of easily obtainable materials and details several classroom experiments as done by his students[2]. In this article Altshuler credits Barbara Sauer from Kentwood High School in Kent, Washington with providing him a description of how to make such a device during a course for physics teachers at the Virginia Military Institute in 1987. This hovercraft was particularly suited for use in the classroom as it was an indoor hovercraft. Three feet in diameter it could carry a two hundred fifty pound person and was designed for relatively quiet hovering over smooth floors. An airtrack blower provided the pressurized air for lift, and the skirt around the bottom perimeter took the form of a sheet-plastic plenum with large holes near the center of the bottom. Many such hovercraft must have been built and used by physics teachers since that time, but we find very little reference to modifications or uses of Altshuler's human airpuck.

THE PERSONAL HOVERCRAFT

The personal hovercraft described here (see Fig. 1.), is a direct descendent of Altshuler's human airpuck. The approximate dimensions and the circular form as well as many details of the plastic plenum and bumper were taken directly from his article. Our prototype (see Fig. 2.) consisted of just these parts. And, like his airpuck, our prototype was powered by an airtrack blower. Our modifications of his basic design include the addition of two braces to reduce the flexing of the plywood base; weighting the plastic plenum to minimize sounds produced by the hovercraft; the addition of a seat for the passenger that serves to keep the center of gravity of the rider-hovercraft low; the selection and installation of batteries, blower and controller to make the hovercraft self contained and able to operate continuously for periods up to one hour; and the addition of a marking system that records the position of two hovercraft at regular, synchronized time intervals. The hovercraft were used in a cooperative lab for our introductory physics course during the spring term this year. Based on that experience and with the help and suggestions of many students we have developed a variety of useful accessories for the hovercraft. These include a vinyl floor marked with a grid of squares 10[cm] on each side, a simple push stick, and a fishing reel winch that produces constant forces. Fig. 1 shows our hovercraft and several of these accessories.

The personal hovercraft has been used with primary level students as well as our undergraduate physics students. The youngest students took turns riding and enjoyed pushing the hovercraft around whether a person was riding or not. They tended to wonder how far and how fast it would travel and were able to measure distance traveled and travel time in order to calculate the speed. After a brief introduction the undergraduate students working on a basketball court in groups of five to seven did two preliminary experiments in a semi-quantitative fashion. First, they applied two perpendicular forces to someone on the hovercraft and monitored the resulting motion. Then they made the hovercraft and rider move in a circle with approximately constant speed; measuring the period, the centripetal force (with scales) and the radius of the circle. With these data they estimated the total mass of the hovercraft and rider and then measured the mass of the rider and the hovercraft on a balance. Finally, the students designed a quantitative lab on the spot and took data for analysis later. They chose to do experiments such as measuring the frictional forces between the hovercraft and the floor as a function of weight or as a function of speed or measuring the stretch of a spring and the resulting speed of the hovercraft after being launched by that spring. All students at all levels were enthusiastic and involved themselves in the experiments. The faculty member working with the younger students said, "The hovercraft stold the show." The professor working with the undergraduates termed her lab, "The greatest!"

CONCLUSION

The scale of the hovercraft is right for an introduction to the physics of motion. By allowing students to experience the motions, the forces and the torques over time periods of several seconds the connections between concepts are immediate and concrete. With the built in timer marking two hovercraft positions twice every second it is straight forward to analyze those marks in terms of two dimensional position vectors, velocity vectors, acceleration vectors, momentum vectors and force vectors. Speeds, potential energies and kinetic energies can also readily be obtained as functions of time or position from these marks on the floor. Students can organize themselves in groups to study motions modified by one or more constant forces, centripetal forces, or spring forces. Collisions can be studied, floor surfaces can be mapped, hovercraft launchers can be designed and tested, or students can study the operation of the hovercraft itself. In a word the personal hovercraft can generate quantitative data for a wide range of kinematic and dynamic physics experiments. Use of the hovercraft in a laboratory setting stimulates creativity.. and it is fun.

Appendix A: Instructions For Use

Find the switch marked BLOWER under the seat and turn it on. When the hovercraft lifts off sit down on the seat and get your feet on board. Look down at the bubble level and adjust your position until the bubble is in the center. Now look around you. The question that usually comes to mind is, "How do I stop this thing?". When riding a hovercraft the natural state of motion is easily seen to be a constant vector velocity with a constant rate of rotation. A sloping floor will definitely change your velocity vector without changing your rate of rotation, but a push from a bystander will generally change both your vector velocity and your spin rate. You may grab a push stick made of foam so that you can have some control over forces that you apply to yourself. You will soon find out that in order to push yourself you need something to push against. Forces come in pairs that are oppositely directed; forces that affect your motion also affect another object. In addition to Newton's three laws of motion (as mentioned above) it will become obvious that to avoid spinning or tilting the hovercraft you must apply the forces in line with a particular point that is located a few decimeters above the center of the hovercraft. This point is the center of mass of the combination of the hovercraft and your body; it is easier to find this point experimentally, than it is to define it.

When you have learned how to control the motion and attitude of the hovercraft you are ready to do quantitative experiments with one or more hovercraft. Place the hovercraft on the vinyl coordinate flooring and decide what experiment you want to do. Practice the choreography of the experiment a few times. When you are ready to do the experiment turn on the switch under the seat labeled MARKER, this energizes the motor that moves the marker. Then locate the hand held clock transmitter, it should be near the CLOCK TRANSMITTER sign. The marker will hit the floor twice a second for as long as the transmitter trigger is held in the squeezed position. The marker stops when either switch is turned off. Enjoy!

Appendix B: Construction of Personal Hovercraft

The parts shown in Fig. 2 are put together as per the instructions in Ref. 2. The parts labeled in Fig 3. represent our contribution to the hovercraft design and we treat them individually:

Braces: Cut from a two by six spruce stud and attached to the base with glue and screws.

Seat: Made from scraps of the 4x8 sheet of half inch plywood that was used for the bases. This is attached with screws, but no glue, so that it is easy to remove.

Noise Suppression: A spider web pattern Liquid Nails Clear Seal adhesive (Aubuchon Hardware $2.97) was applied to the upper side of the 4 mil polyethylene sheet before it was attached to the base.

Batteries: Hawker Energy, Pure Lead Tin Monoblock Type 0859-0012, 6[V] 8[A hour]. (Allied Electronics #221-0012 ~~$20.74)~~ 17.10 Four batteries for each hovercraft. BAT NETWORK G 682

Blower: AMETEK #11645-00 Three stage 24[V] 10[A] three phase DC blower. Output 20[ft3/min] at a pressure of 20[inch (water)]. (C&H Sales, Stock #DCB9601 $12.50) Attached by three bolts to a brace with the output pressed into the hole through the base of the hovercraft.

Blower Controller: W.W.Grainger Blower controller with heat sink #3HV53, ~~$193.59~~ 227.75. 781-7525 193.59
Screwed to the base. A hole 1[cm] by 5[cm] was made at the base of the brace where the blower was attached and the wiring harness from the controller to the blower was passed through this hole.

Radio Controlled Timer/Marker: A National Semiconductor LM555CN-ND timer integrated circuit (Digikey $0.56) is used to provide a clock signal to a 49.86[MHz] FM radio transmitter. The clock signal is picked up by an FM receiver mounted on the hovercraft that controls a motor that pushes a marker against the floor. The transmitter, receiver and motor assembly are a radio controlled car, somewhat modified. New Bright Radio Control 1:24 Scale Sports Car #346 (Ben Franklin $12.99). Markers are Crayola Washable Markers #7809, Package of 8. (Ben Franklin $3.99).

Vinyl Flooring: A square three yards on a side. (Countryside Carpet and Paint $90.00). Any plain, light colored, smooth flooring that will lie flat will do.

Push Stick: Life-Like Products, Wacky Noodle (Ben Franklin $2.99) a 7[cm] diameter rod of high density foam 1.6[m] long.

Constant Magnitude Force Winch: A Diawa fishing reel (Outdoor Sports Model 3500 Regal-X $63.59) is attached to the handle section of a rod (Outdoor Sports Free). Drag is adjusted by a knob with numbers on the front of the reel.

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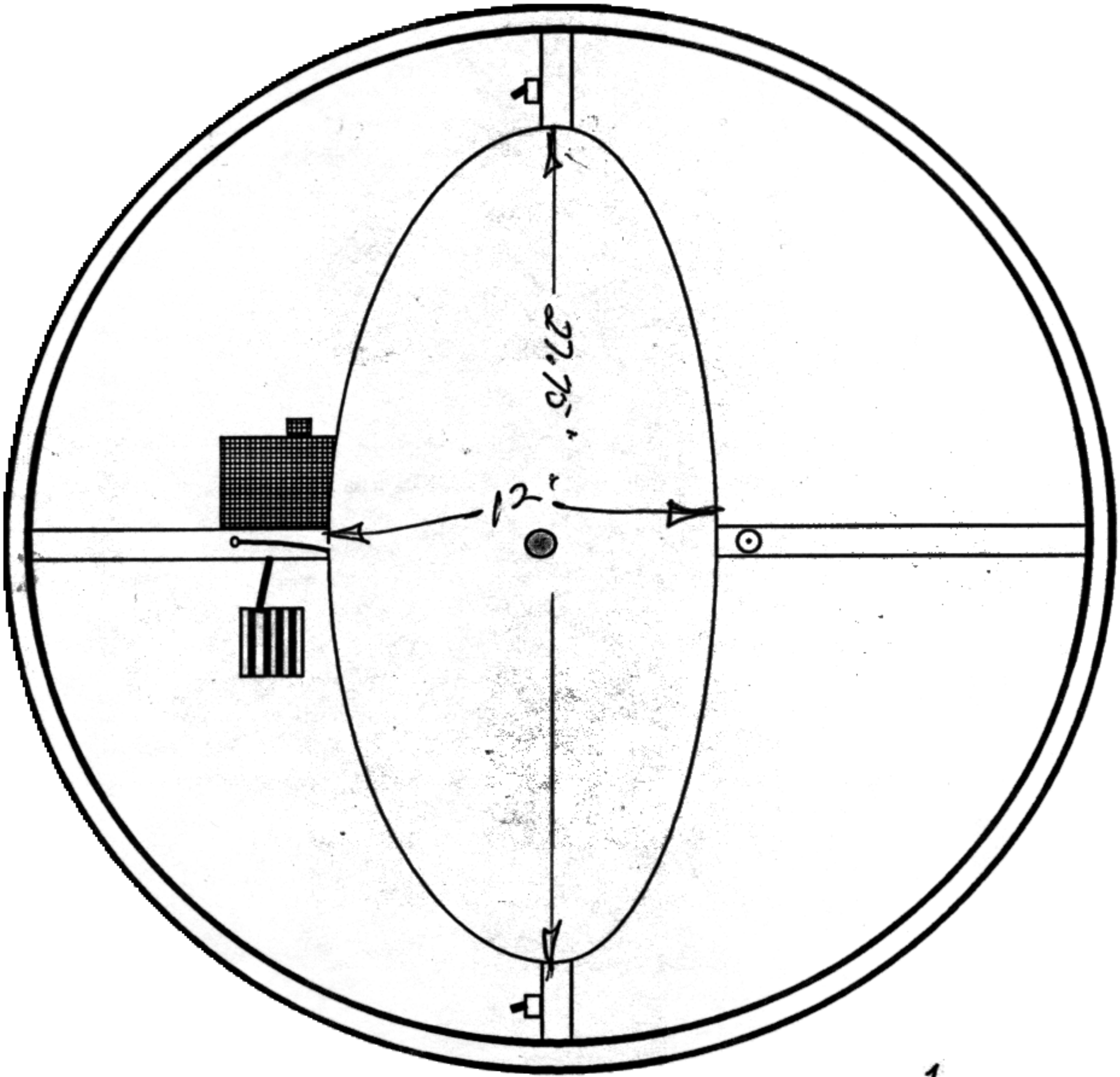
[1] For example start at http://www.hovercraftofamerica.org/ or do a search on "hovercraft".

[2] Ken Altshuler, "The Human Airpuck" , *Phys. Teach.*. **27** , 615-617, (Nov 1989).

Fig.1(a). Hovercraft Top View



SCALE 2 1

(b). Side View

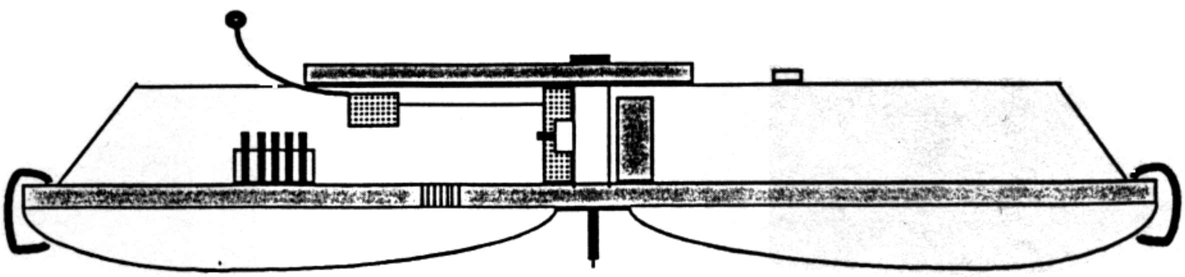
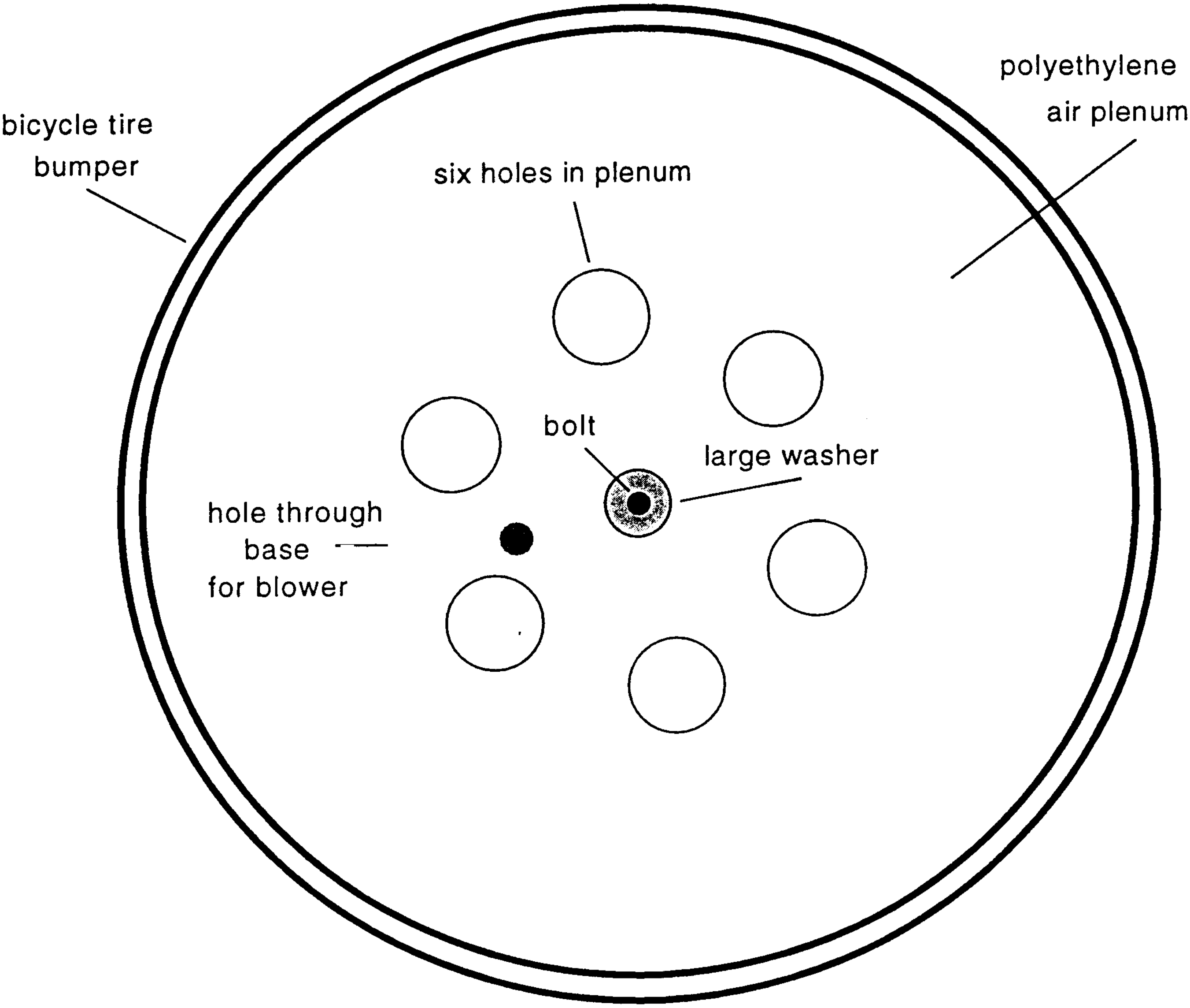


Fig. 2(a) Airpuck Bottom View



(b). Side View

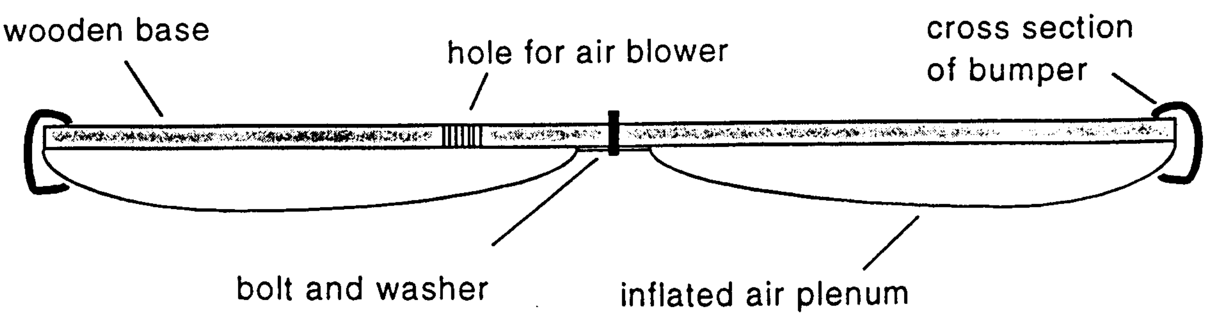
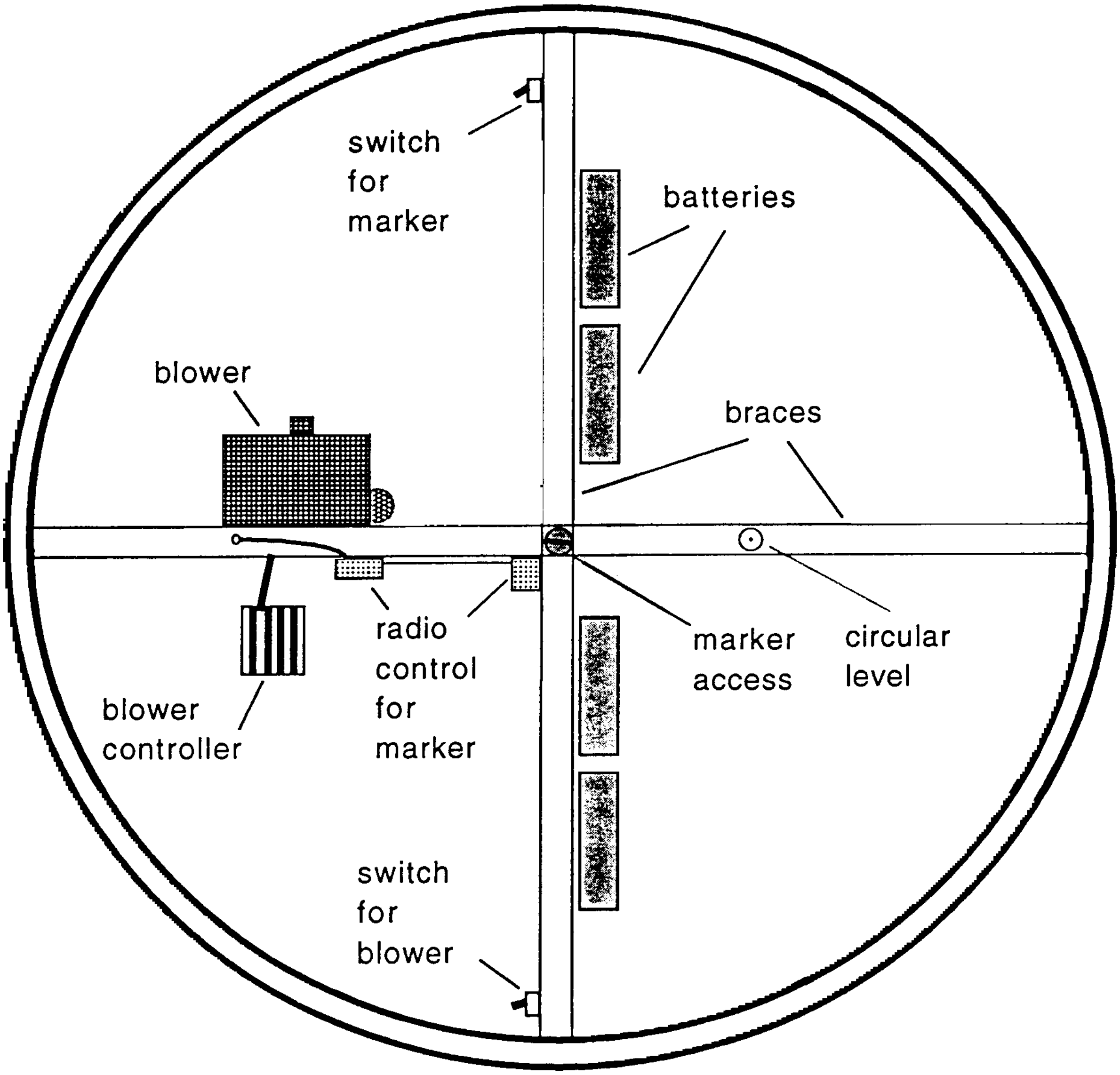
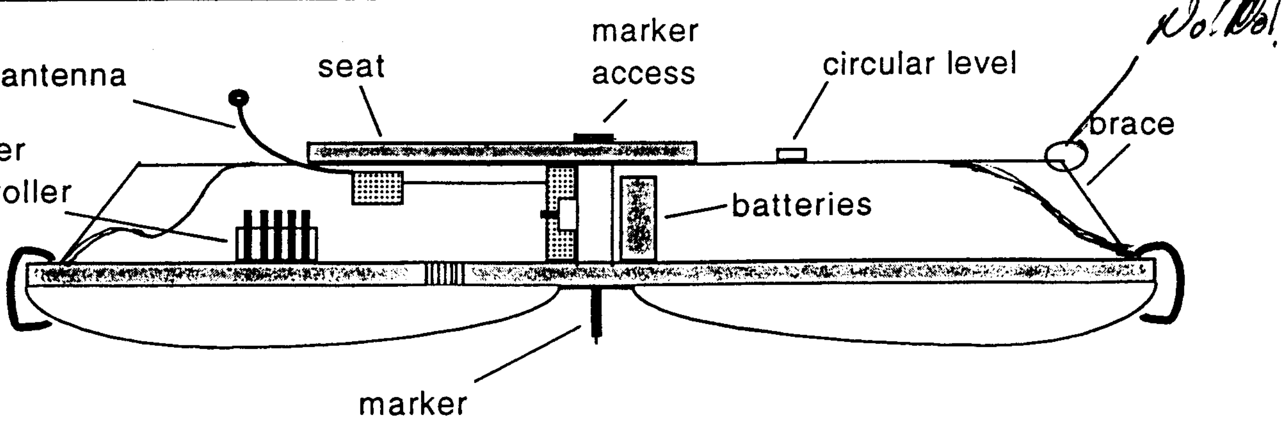


Fig. 3(a). Hovercraft (Seat Removed)



(b). Side View



Attn Ernest Provo
413-538 2357

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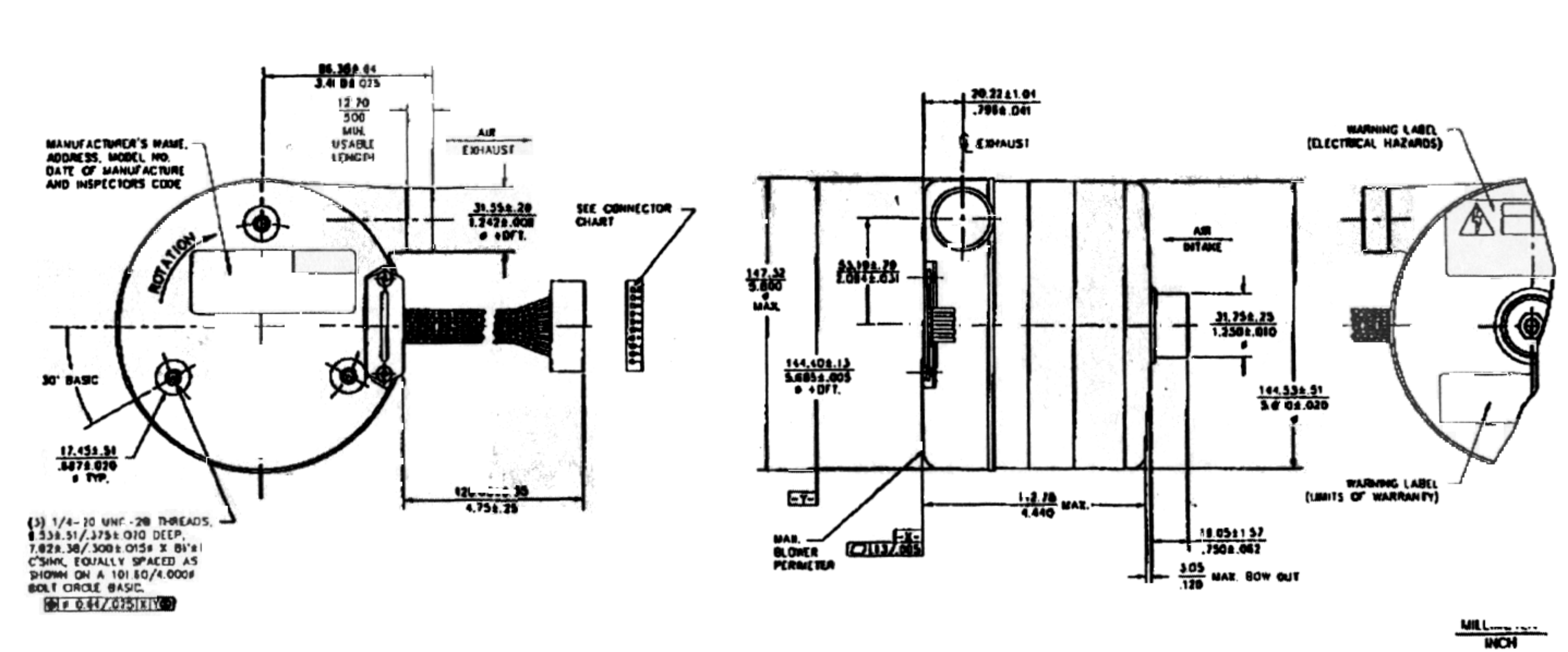
NOTES:
(1) RIBBON CABLE: #18GA, 8 CONDUCTOR LEAD (19 X 30AWG), 105°C, PVC, 300VRMS RATING.
(2) TERMINAL HOUSING: .156 INCH CENTERS, 8 CIRCUITS WITH LOCKING RAMP, MOLEX 26-03-4101 OR EQUIVALENT.
(3) TERMINALS: MOLEX, TIN PLATED, TRIFURCON #08-50-0187 OR EQUIVALENT.
(4) KEY: MOLEX #01-00-3801 OR EQUIVALENT.



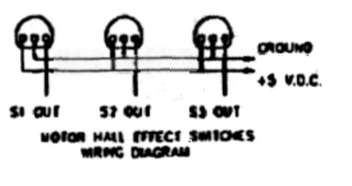
MOLEX CONNECTOR
TERMINAL POSITION INSTALLATION CHART

PIN #10	MOLEX KEY (SEE NOTE 4)
PIN #9	S1 OUT (GRAY)
PIN #8	S2 OUT (PURPLE)
PIN #7	S3 OUT (BLUE)
PIN #6	+ 5V.D.C. (GREEN)
PIN #5	GROUND (YELLOW)
PIN #4	COIL "A" (ORANGE)
PIN #3	COIL "B" (RED)
PIN #2	COIL "C" (BROWN)
PIN #1	MOLEX KEY (SEE NOTE 4)

TIMING DIAGRAM FOR CW SHAFT ROTATION
(VIEWED FROM SHAFT END)

DEGREES (MECHANICAL)	0–30	30–60	60–90	90–120	120–150	150–180	180–210	210–240	240–270	270–300	300–330	330–360
COIL A	OFF	-	-	OFF	+	+	OFF	-	-	OFF	+	+
COIL B	-	OFF	+	+	OFF	-	-	OFF	+	+	OFF	-
COIL C	+	+	OFF	-	-	OFF	+	+	OFF	-	-	OFF

COIL DIAGRAM



MOTOR HALL EFFECT SWITCHES WIRING DIAGRAM

MILLIMETER
INCH

CONTROLLER REQUIRED

75511

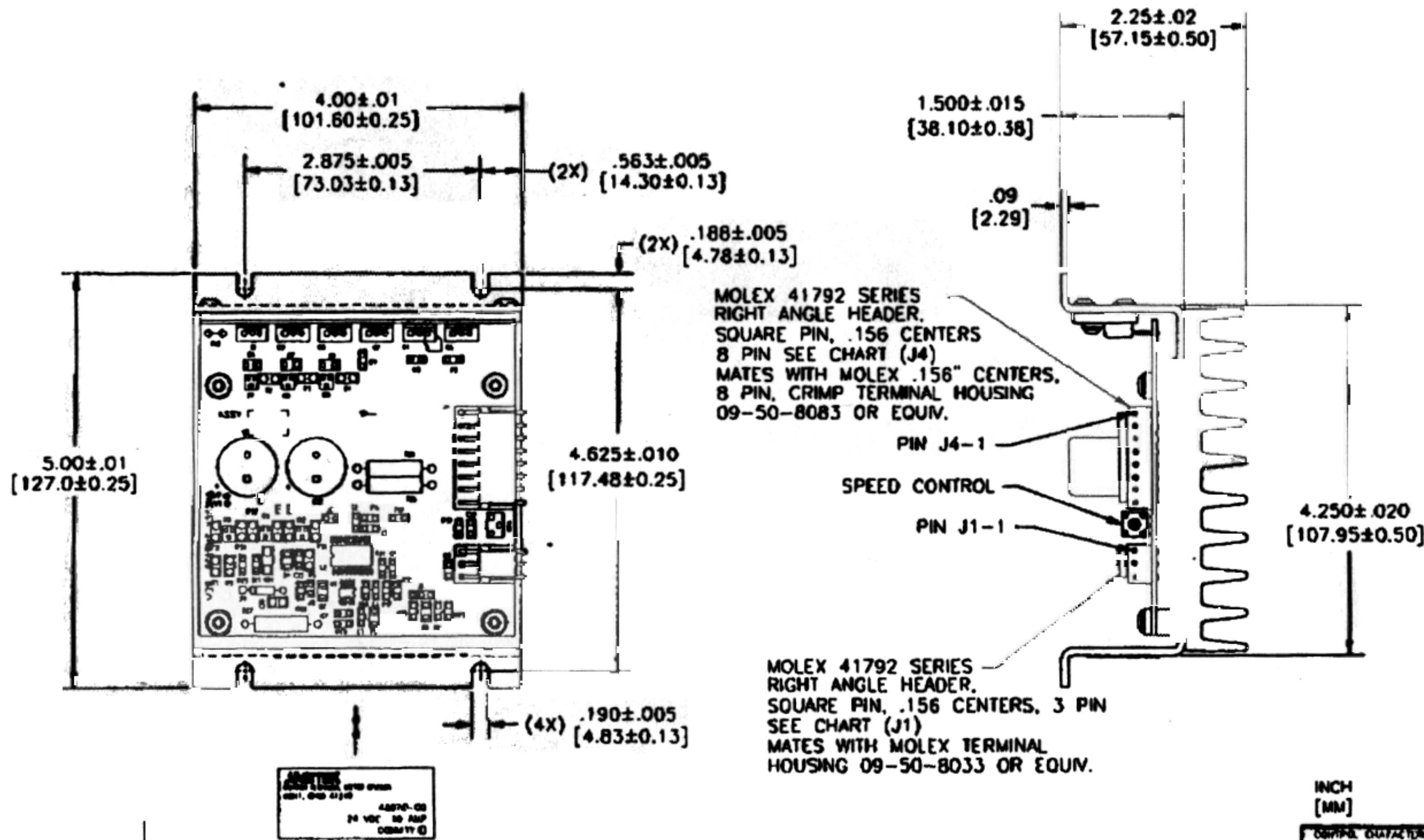
OUTLINE 5.7, 3 STAGE BRUSHLESS DC BLOWER 24 V

AMETEK

116450-00-0

DWG. NO. 48070-00-0 REV. B

NOTES:
1. ELECTRICAL SPECIFICATION 48070-00-0 (48070ESP.DOC) REQUIRED WITH THIS DRAWING.
2. REFER TO DOCUMENT 4930740 FOR CONTROLLER USERS MANUAL.
3. PROTECTION FUNCTIONS: CURRENT LIMIT AND THERMAL PROTECTION.



INCH
[MM]

CONTROLLER

SOCKET POSITION	DESIGNATION	MOTOR
J4-1	PHASE A	ORANGE
J4-2	PHASE B	RED
J4-3	PHASE C	BROWN
J4-4	HALL GND	YELLOW
J4-5	HALL+ 12V	GREEN
J4-6	HALL 1	GRAY
J4-7	HALL 2	PURPLE
J4-8	HALL 3	BLUE

SOCKET POSITION	DESIGNATION
J1-1	VIN (+24V)
J1-2	GND
J1-3	ANALOG SPEED-IN

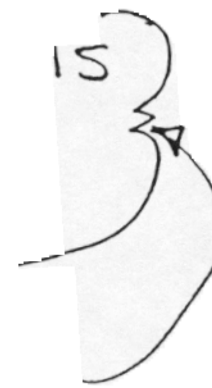
OUTLINE DRAWING

AMETEK

DCB 960

4GN 3075 U IN UNT 15

3 75 EQUAUALENT



YEL HALL GR. UND

GRN = HALL + SUPPLY

BLU = HALL OUT C

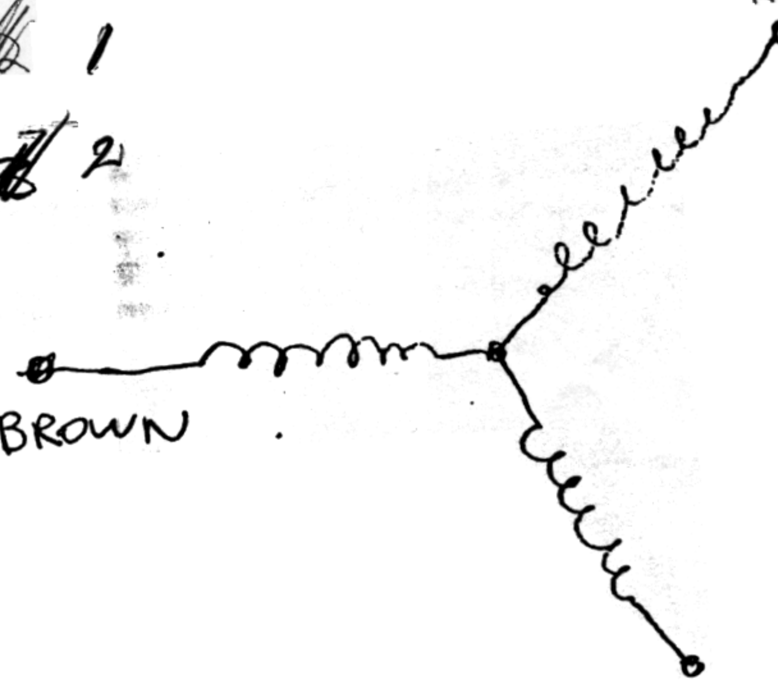
PURP HALL OUT

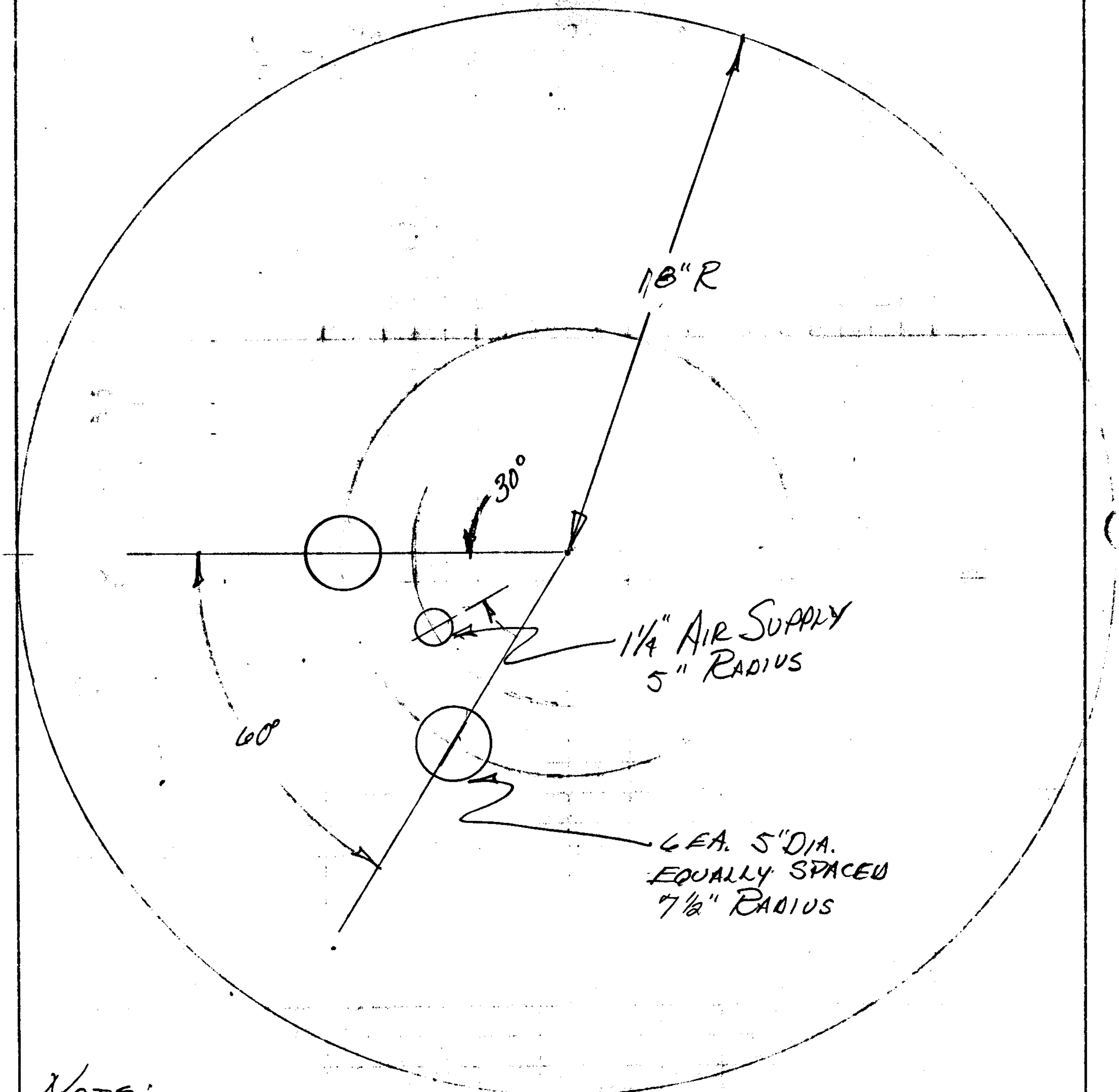
GRAY HALL O T

BROWN Φ 3

RED Φ 1

ORN Φ 2

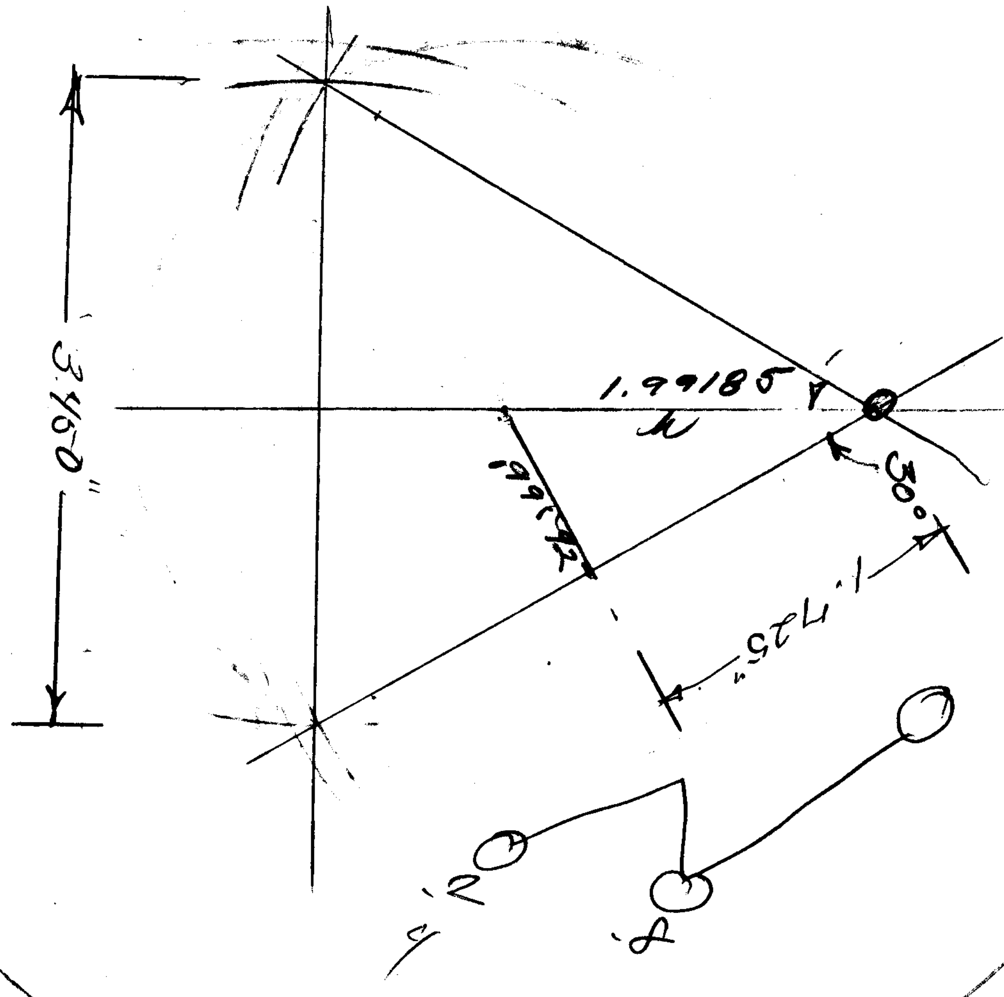




NOTE:

BLOWER OUTLET TO
SKIRT OUTLET RELATIONSHIP.

DEPARTMENT OF PHYSICS
MOUNT HOLYOKE COLLEGE
SO. HADLEY, MASS. 01075



$$\cos 30^\circ = \frac{1.725}{x} = 1.99185$$

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ER BLOWER MOTER MOUNTING HOLE PATTERN