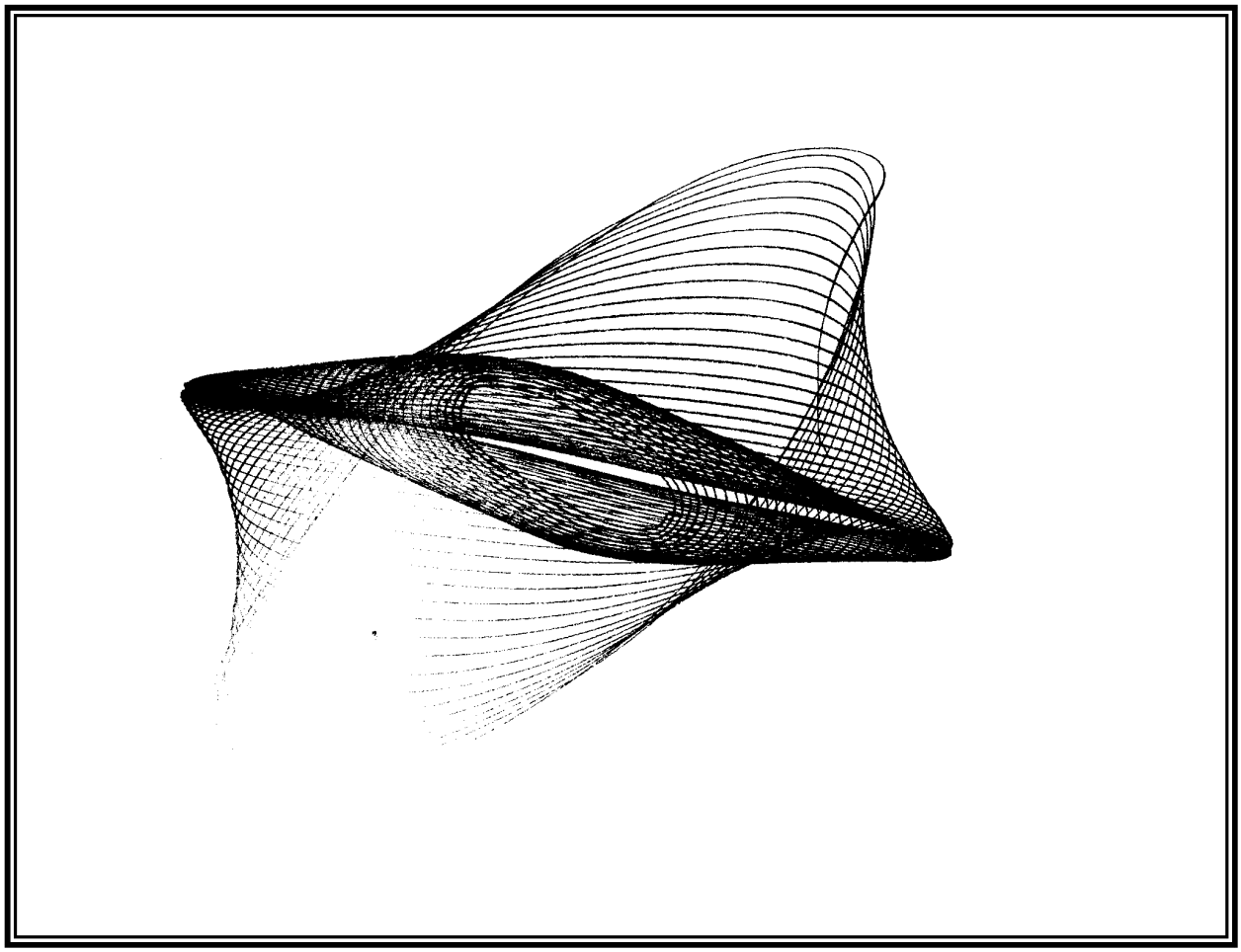
Building Intergalactic"s

Twin-Pendulum

H A R M O N O G R A P H

By SAMUEL W VALENZA, JR.



All parts for this machine were purchased at local retail outlets; i.e., hardware stores and hobby shops. Please read instructions thoroughly before attempting construction.

I. Frame Assembly

Refer to Drawing No. 100 to familiarize yourself with the Frame Assembly. The critical part of the frame assembly is the FULCRUM ASSEMBLY, Drawings No. 101, 102. If possible, this piece may be cut and drilled from one piece of 3/4" hardwood. In our machine, we assembled it as shown from 3 pieces, using glue and screws. After the fulcrum assembly is completed, the dowels should be cut to indicated lengths (see parts list for Drawing No. 100). If you are handy with solder and wish to go to the expense, 1/2 " copper tube (hard) may be used instead of wooden dowels. For convenience and strength, elbows indicated in Drawing No. 101 should be drilled after assembly and thru-bolted to the dowels with 4-40 x 1" round head machine screws, washers and nuts.

After all dowels have been cut, and fulcrum assembly is cut and drilled, assemble the frame and drill elbows with dowels inserted to ensure proper alignment. The frame will be shaky until stiffeners are added, and some tuning and adjustment may be necessary to obtain proper rigidity. Place pendulum weights (or some other 20-pound weight) on fulcrum assembly during drilling and tuning process to ensure that the frame is settled into a position it would acquire with pendulums in place. The frame must be rigid or kinetic energy will be transferred to the frame during operation, thereby dampening motion of the pendulums.

The fulcrum assembly should be drilled using a 9/64" dia. drill at the six points(6) where the frame assembly legs are attached and a sheet metal screw of appropriate size (No. 6-40) used to insure rigidity of the fulcrum assembly. These screws will thread themselves through the wood and the 45' elbow at the top of the leg.

II. Knife Edges

The knife edge assembly is made from a 2-inch long 1/4" brass pipe nipple, two brass flat washers, a 1/4" brass angle, and brass strip obtained at a local hobby shop. American Standard ¼" pipe has an outside diameter of .540 inches. Standard flat washers for ½" bolts have an inside diameter of 17/32 (.5 3 1) and outside diameter of 7/8 or 1-1/16 inches. If you can obtain the heavy washer in this size (I.D.-17/32", O.D.-l- 5/8" you can save one step in assembly. We were not able to find this size in brass.

The brass nipple and washer must be aligned in a vise or metal jig of some sort and soldered using a heavy duty soldering iron or torch. An alternative to this step would be to thread the nipple using a thread-cutting die and attaching the washer between two hex nuts. After the smaller washer is attached to the nipple, the larger washer should be soldered to it, being careful to align the washers concentrically. The angles are attached using 4-40 x 1" round head machine screws, lock washers, and nuts after drilling the washers and angle brass. Angle brass is best cut using a hacksaw and laying it over the comer of a piece of wood so that the wood fills the angle. Knife edges are then cut to length, filed on one edge at an angle to create the knife edge, clamped to the angle brass, drilled and attached using 4-40 x 1 " round head machine screws, spring lock washers and nuts. Each knife edge should be attached with two screws for strength. This step can be eliminated if one can obtain 1 x 1 " angle brass from which to fashion the knife edges.

Knife edges are attached to the knife ring assembly in the same manner as for the knife edge assembly.

III. Pendulum Assemblies

The brass sheets should be cut to size (refer to parts list, Drawing No. 103) and drilled with a ¼" hole in their centers (to accept threaded rod).

Four evenly spaced holes should be drilled (1/8"diameter) in the 4 x 4" sheet for attachment of the writing table.

A 1/4" brass nut should then be soldered concentrically in alignment with the hole in the 4 x 4" sheet. The plastic writing table should be next aligned with the brass sheet and drilled for fastening screws, the topside of these screwholes being countersunk to accept four 4-40 x 1 " brass flat-head screws.

The next step is to drill the 4 x 6" brass sheet exactly in its center (1/4" diameter) and in the two positions where the writing arm supports are located. These 1/8" diameter holes are located on the longitudinal centerline of the rectangle, 2-3/16 inches either way from the center.

IV. Writing Arm Assembly

Refer to Drawing No. 105 and draw the writing arm supports on a sheet of 26 gage brass. Cut these out with tin shears, and use a sharp straight metal edge to bend them as indicated in Drawing No. 104, Item No. 7. They must be drilled as shown.

Cut the writing arms from the ¼" plastic rod and drill two holes to accommodate screws from the writing arm support. See Drawing No. 106 for dimensions. Mount the writing arm supports and the writing arms, and mark the writing arms for the 4-40 x 1" screw that holds them together. It is suggested that the writing arm and writing arin support be assembled on top of a large sheet of paper so that you can align these parts as accurately as possible. Draw a long straight line on the paper (about 30") and a perpendicular transversal about 20" from one end. If you drill and assemble the writing arm on top of this sketch you can assure that the balance arm is collinear with the writing arm, and that the stiffeners are perpendicular to the writing and balance arms.

When the 4-40 screw and nut located at the end of the writing arm is fastened securely, the writing arms will be bent slightly inward, creating tension in the unit. Mount the writing arms in the writing arm supports and with the writing arms bent, locate and mark the writing arm stiffeners for drilling. After drilling, attach the stiffeners using 4-40 x 1" screws, washers and nuts.

Next, locate and align the balance arm and mark for drilling. Drill and attach using 440 x1" screws, nuts and washers. Finally, attach the coping saw blades using scotch or masking tape. The coping saw blades serve to prevent the balance weights from sliding on the balance arm.

Washers or any moderately heavy objects having a centered hole of about -1 " diameter will serve as balance weights.

V. Pendulum Weights and Rod

The pendulum weights must be fabricated unless bobs of suitable weight can be found in a junkyard or antique shop. It is not difficult to make weights from old lead or zinc scrap (about 10- 11 lbs. for each pendulum), however.

Find a suitably-sized can five or six inches in diameter and three or four inches deep (film cans and tuna cans are excellent). Remove the top or lid and place a 3" galvanized 1/4" pipe nipple vertically over the center. Melt the scrap lead and zinc in a cast iron pot and remove surface scum with a wooden spoon, then pour a small amount of molten lead around the base of the pipe nipple to hold it in position. Finally, pour

the remaining lead in one continuous pour, filling the can to your satisfaction.

Since lead weighs 0.406 lbs. per cubic inch, you may readily calculate the weight of your pendulum bob using the volume formula for a right circular cone.

It is handy to have the pendulum bob quickly removable without changing its position on the pendulum rod. This is accomplished by cutting two shorter pieces of -1 “ threaded rod (approximately I I" long) and joining these to the longer pendulum rod using-a threaded rod coupler.

VI. Operation of the Harmonograph

Since the period of the pendulum is a function of its length and bob weight, many adjustments are possible, creating various kinds of drawings. A Flair or Bic pen may be used for best results, being attached to the writing arm with a small rubber band.

After some experimentation, you will discover that the difference in pendulum lengths affects the distance between lines on the drawings. With 10-pound bobs and large sheets of paper it is possible to make drawings of considerable amplitude, covering almost the entire drawing area.

It is important that all screws and nuts be tight to prevent wobble in the motion of the pen. The knife edge ring assembly must be scored at right angles to its own knife edges with a small file or hacksaw blade to prevent the upper knife edge from “walking.” In a similar way, the collars attached to the fulcrum assembly should also be scored to receive their knife edges.

The best way to operate the harmonograph is to raise the writing arm, insert a sheet of paper, and start the writing table pendulum. Keeping the pen up, but holding it lightly, start the writing arm pendulum in motion and lower the pen to the drawing paper. After some trial and error, you will discover the best setting for the balance arm weights, and the kinds of motion to impart to the pendulums to achieve delightful and satisfying drawings.

VI I. Geometry of the Frame Assembly

- TETRAHEDRON (2), WITH ISOSCELES TRIANGLES (3) AS FACES.
- RECTANGULAR FACES (4)
- RIGHT RHOMBOID CYLINDER
- BASE: EQUILATERAL TRIANGLES (2) SHARING SIDE DB.

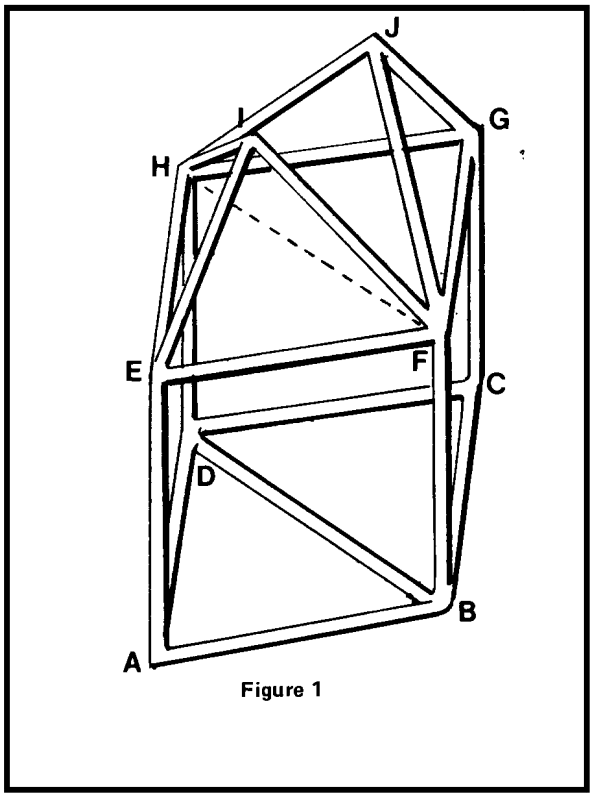


Figure 1

Lengths of components:

h_1 = distance from I or J to plane containing E, F, G, H. (Fig. 2).

h_2 = length of $\overline{EA}$: (Fig. 1, 2).

r_1 = distance from vertex to intersection of altitudes in AEFH, AHFG. (Fig. 3).

r_2 = length of edge of tetrahedron. (Fig. 4).

s = length of $\overline{EF}$, $\overline{FG}$, $\overline{GH}$, $\overline{HE}$, $\overline{AB}$, $\overline{BC}$, $\overline{CD}$, $\overline{DA}$. (Fig. 1, 3).

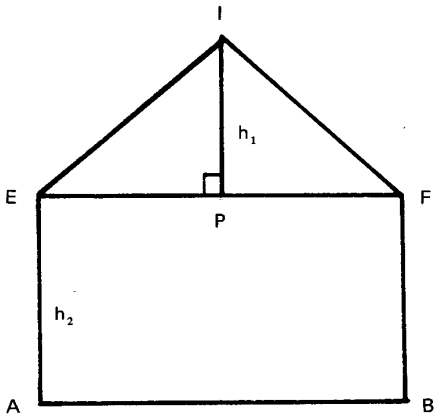


Figure 2

Equations for Frame Assembly:

$$\frac{r_1}{2} = \frac{\frac{s}{2}}{\sqrt{3}}$$

(1) $$r_1 = \frac{s\sqrt{3}}{3} = .577s$$

$$r_1 = r_2 \cos 45$$

(2) $$r_2 = \frac{r_1}{\cos 45} = \frac{\frac{s\sqrt{3}}{3}}{\frac{1}{\sqrt{2}}} = \frac{s\sqrt{6}}{3} = .816s$$

$$h_1^2 = r_2^2 - r_1^2 = \left(\frac{s\sqrt{6}}{3}\right)^2 - \left(\frac{s\sqrt{3}}{3}\right)^2$$

$$h_1^2 = \frac{6s^2}{9} - \frac{3s^2}{9} = \frac{s^2}{3}$$

(3) $$h_1 = \sqrt{\frac{s^2}{3}} = .577s$$

since $h_1 = r_1$, $\angle$EIP is 45 degrees

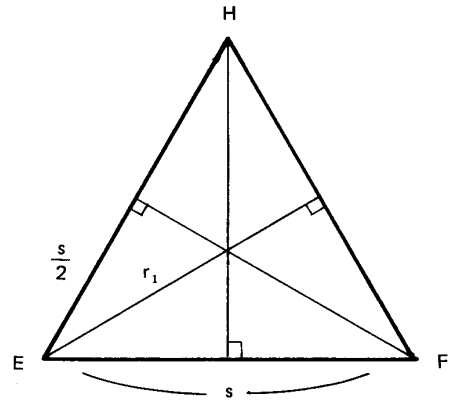


Figure 3

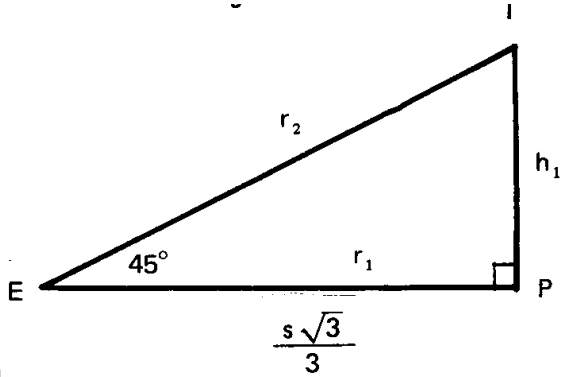


Figure 4

Motion of a simple pendulum

The force of gravity acts on the bob to restore the pendulum to a position of equilibrium. The force thus generated is expressed by:

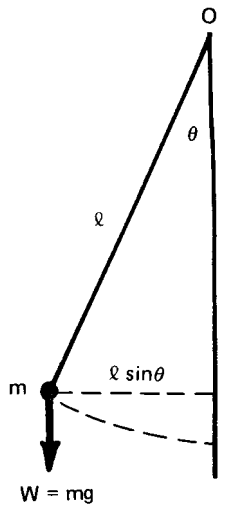
(4) $L = -mgl\theta$

The negative sign expressing that the motion of the bob is counter to the magnitude of the angle θ.

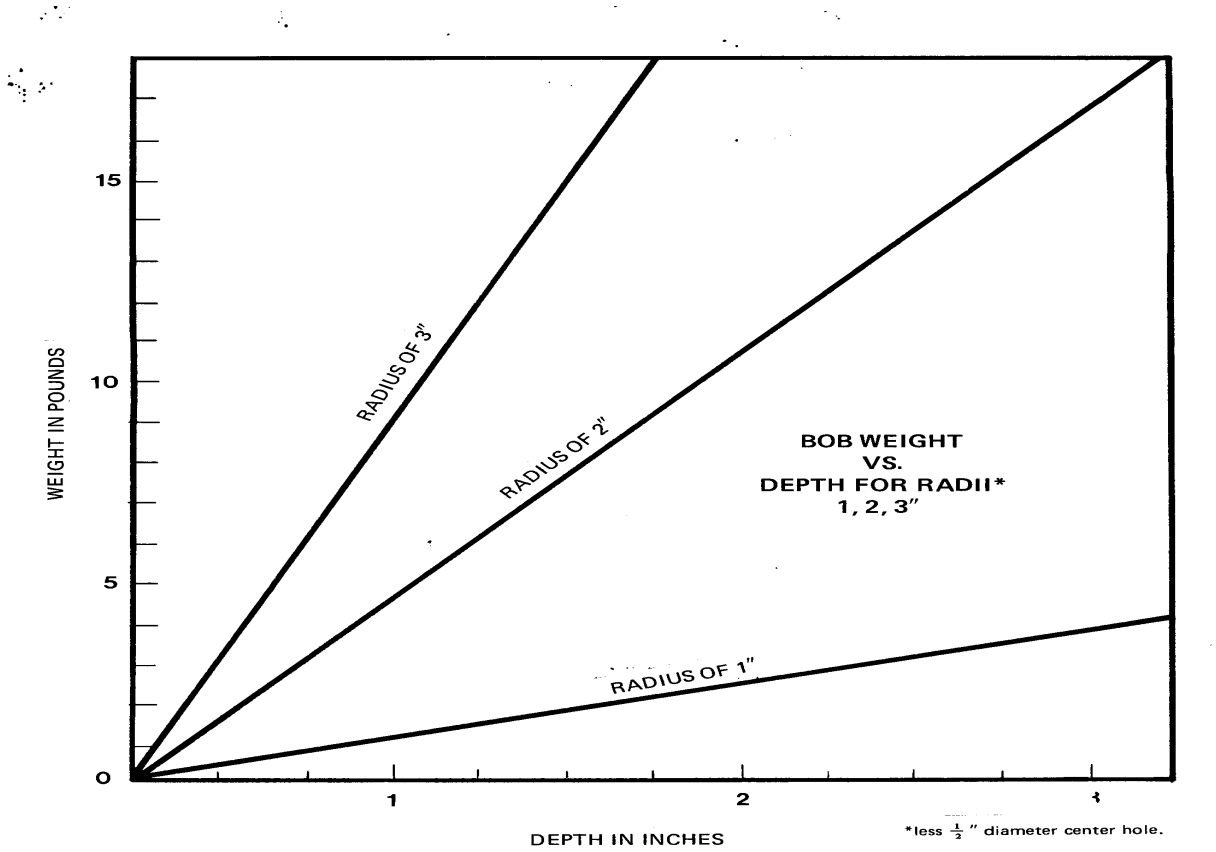
The frequency of the pendulum is given by:

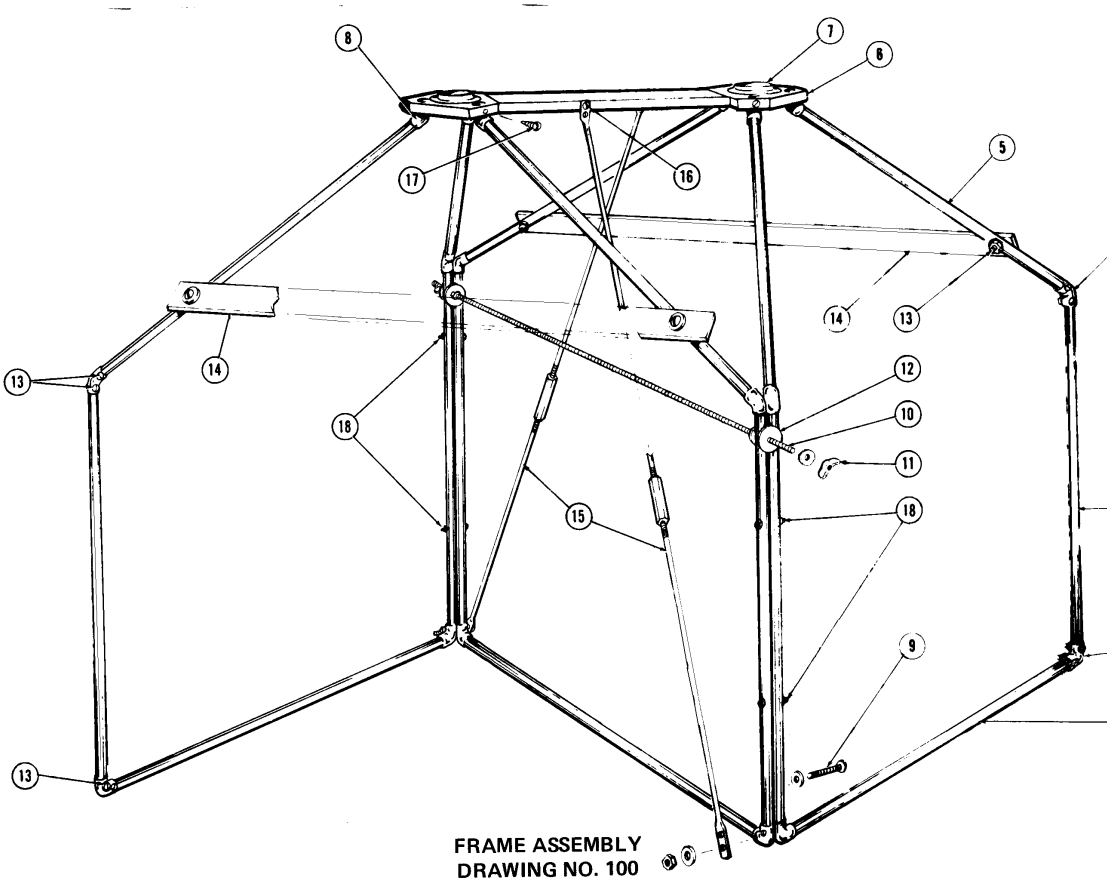
(5) $f = \frac{1}{2\Pi}\sqrt{\frac{g}{l}}$

which tells us that the frequency of a simple pendulum is independent of its mass. The above expression may be utilized to approximate the force of gravity by measuring f and l

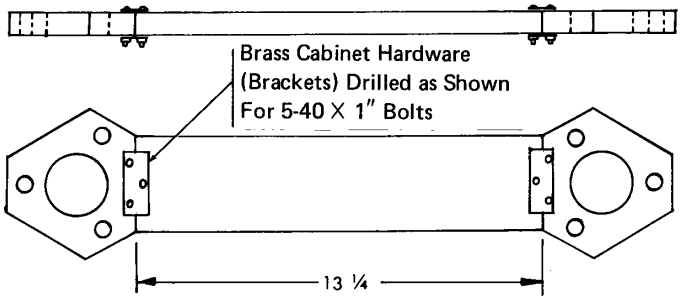


• Figure 5



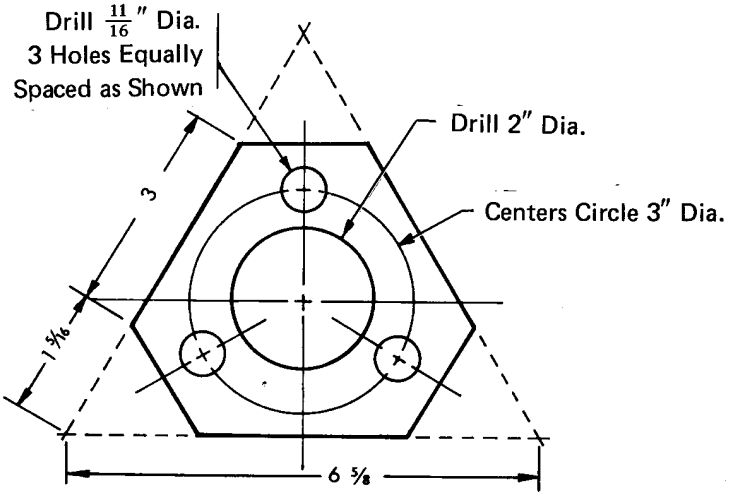


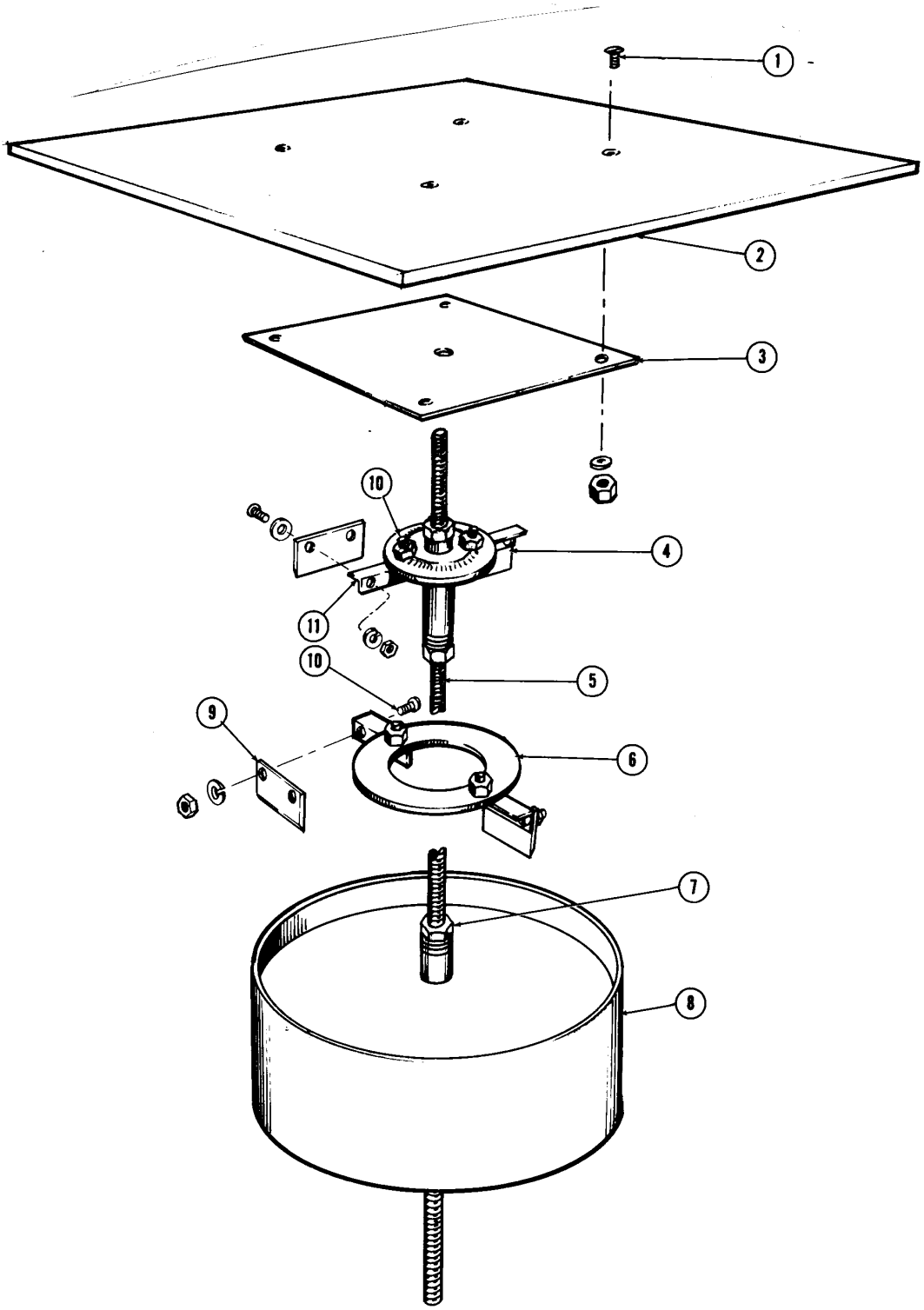
FRAME ASSEMBLY
DRAWING NO. 100



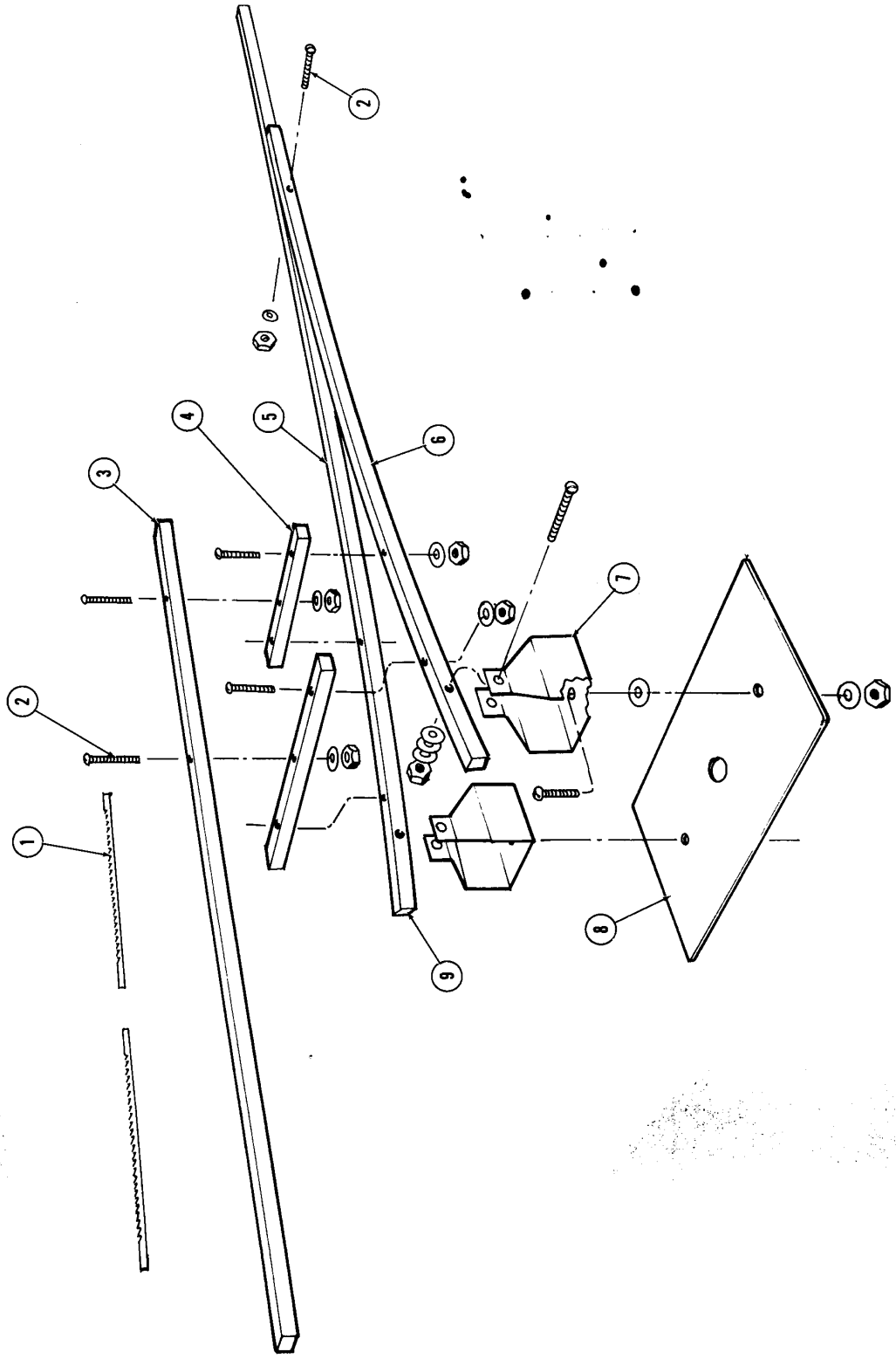
FULCRUM ASSEMBLY
DRAWING NO. 101
(From $\frac{3}{4}$" Hardwood)

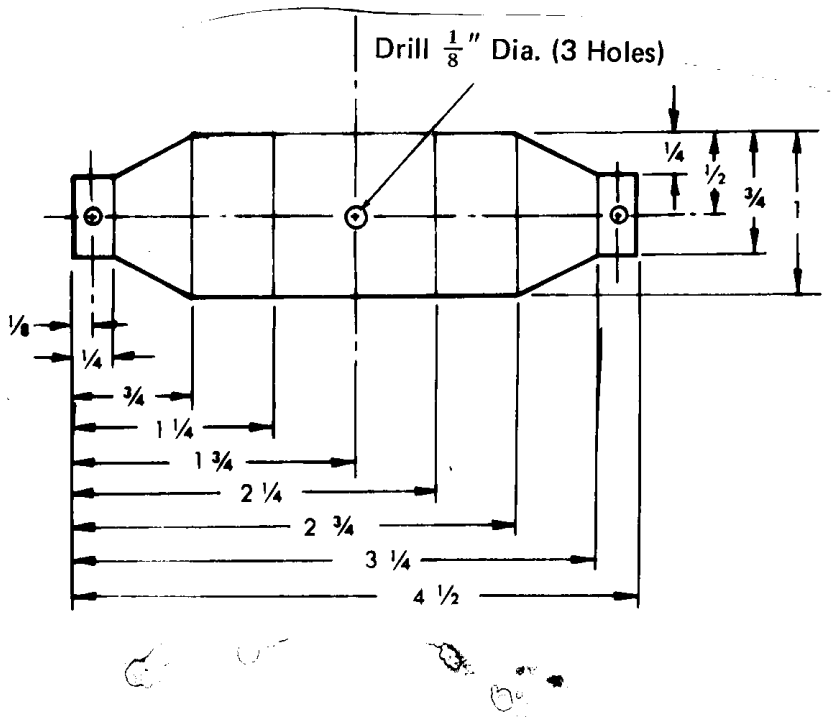
All dimensions are in inches.





PENDULUM ASSEMBLY
DRAWING NO. 103


WRITING ARM ASSEMBLY
DRAWING NO. 104



WRITING ARM SUPPORT
DRAWING NO. 105

PARTS – FRAME ASSEMBLY

DRAWING NO. 100

NUMBER	DESCRIPTION	NUMBER REQUIRED
1	Dowel, wood, $\frac{5}{8}$" dia. X 27-$\frac{1}{2}$" long	3
2	90° elbow, copper, $\frac{1}{2}$" (female)	6
3	Dowel, wood, $\frac{5}{8}$" dia. X 21-$\frac{3}{4}$" long	6
4	45° Elbow, copper, $\frac{1}{2}$" (female)	6
5	Dowel $\frac{5}{8}$" dia. X 20-$\frac{3}{4}$" long	6
6	Fulcrum Assembly. See Drawings No. 101, 102.	1
7	Curtain rod holder, brass plated, 2-$\frac{5}{16}$" dia. with 1-$\frac{1}{2}$" dia. X $\frac{3}{8}$" high collar.	2
8	45° Elbow, copper, $\frac{1}{2}$" (male-female).	6
9	Screw, machine roundhead, 5-32 X 1-$\frac{1}{2}$", with washers, nut.	4
10	Stiffener, threaded brass rod $\frac{1}{8}$" dia. X 30" long	1
11	Nut, wing, $\frac{1}{8}$" thread	2
12	Washer, plain, $\frac{7}{8}$" dia. with $\frac{5}{16}$" dia. hole	2
13	Screw, machine, roundhead, 4-40 X 1" with washers, nut.	12
14	Stiffener, wood trim, 1 X $\frac{1}{4}$ X 20" long	2
15	Turnbuckle, screen door, aluminum and zinc, 42" long.	2
16	Screw, wood, No. 4 X $\frac{3}{4}$" long	2
17	Screw, self-tapping, No. 6-40	6
18	Screw, machine, roundhead, 4-40 X 1$\frac{1}{2}$" with washers, nut	4

PARTS – PENDULUM ASSEMBLY

DRAWING NO. 103

NUMBER	DESCRIPTION	NUMBER REQUIRED
1	Screw, flat-head, 4-40 X $\frac{1}{2}$", with flat washer, nut.	4
2	Table, drawing, acrylic plastic (Plexiglas), 12 X 12 X $\frac{1}{4}$" thick.	1
3	Brass, sheet, 4 X 4 X .0159" thick (26 gage).	1
3-A	Brass, sheet, 4 X 6 X .0159" thick (26 gage).	1
4	Knife Edge Assembly.	2
5	Threaded rod, galvanized steel, $\frac{1}{4}$" dia. X 36" long.	2
6	Knife-edge ring assembly.	2
7	Nut, $\frac{1}{4}$" steel.	4
8	Weight, Pendulum.	2
9	Knife edge, from $\frac{1}{2}$" X 20 gage brass sheet	4
10	Screw, machine, roundhead, 4-40 X $\frac{1}{4}$" long with spring lockwasher, nut	12
11	Angle, brass, $\frac{1}{4}$ X $\frac{1}{4}$" X 26 gage	4

PARTS – WRITING ARM ASSEMBLY

DRAWING NO. 104

NUMBER	DESCRIPTION	NUMBER REQUIRED
1	Blades, coping saw.	2
2	Screw, machine, round head, brass, 4-40 X $\frac{3}{4}$" long with flat washer and nut.	9
3	Balance arm, acrylic plastic, (Plexiglas) $\frac{1}{4}$ X $\frac{1}{4}$ X 16" long.	1
4	Stiffener, balance arm, acrylic plastic (Plexiglas) $\frac{1}{4}$ X $\frac{1}{4}$ X 4" long.	1
5	Writing arm, acrylic plastic (Plexiglas) $\frac{1}{4}$ X $\frac{1}{4}$ X 22" long.	1
6	Writing arm, acrylic plastic (Plexiglas) $\frac{1}{4}$ X $\frac{1}{4}$ X 18" long.	1
7	Support, writing arm, from brass sheet .0159 thick, (26 gage) refer to drawing No. 105.	2
8	Table, writing arm, brass sheet, .0159 thick, (26 gage) 4 X 6" long. Drawing No. 105.	1
9	Stiffener, balance arm, acrylic plastic (Plexiglas) $\frac{1}{4}$ X $\frac{1}{4}$ X 6" long.	1