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PROGRESS REPORT NO. IV

PROCESSING OF SUGAR BEETS

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ABSTRACT

This report describes the design and construction of continuous equipment for disintegrating sugar beets to a fine pulp from which the juice can be removed by filtration or centrifuging followed by washing.

In addition to the design of the continuous disintegrator, the report describes the construction of accessory experimental equipment such as a beet cutter, beet slicer, cossette mixer, and feeder. The experimental technique to be used as well as the instrumentation are presented in detail.

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BRIEF SUMMARY OF THE PREVIOUS WORK

In the period covered by Progress Report III, a number of experiments were performed in which the "explosion" juice as well as the diffusion juice were subjected to the standard purification process and the characteristics of the juices compared. To insure good comparison in each series of experiments, one half of each beet of a given sample was used for the explosion and the other half was used for the preparation of the diffusion juice in a small-scale diffusion battery.

The "explosion" juice was prepared by first steaming the cossettes with saturated steam (at 0 psig) and then suddenly increasing the steam pressure to 55 psig and ejecting the steamed cossettes against a vertical baffle by release through a quick-opening valve. The juice from the resulting pulp was recovered by centrifuging and washing. The time of contact of the high-pressure steam with cossettes was estimated to be less than 1 second. The time of steaming at atmospheric pressure varied with the quality of the beet from 1 to 6 minutes.

It has been found that by limiting the time of steaming, good-quality juice can be prepared by this process. A comparison of the quality of thin juices (see Progress Report III, Table IV, Runs II and III) shows that the thin juice obtained by the explosion method compares favorably with that prepared from the diffusion juice. There seems even to be a tendency on the part of the "explosion" juice to yield thin juices of higher purity. The best recovery obtained in the preliminary experiments (Progress Report III, Table VI) was 94.3 percent of sugar in the beet at a draft of 117 percent by weight. This is a very encouraging figure considering that only two types of baffles have been investigated and that the optimum conditions of the disintegration have not yet been determined. Changes in the process conditions and the use of a continuous equipment should make it possible to increase the degree of disintegration and the recovery of sugar from the beets substantially.

The purity of the "explosion" juice (as determined on a refractometer) after washing of the cake was in five runs equal to or even slightly higher than the purity of the hot digestion juice which was used as a reference juice in the recovery tests. In only one run did the "explosion" juice show a decrease of purity.

DESIGN AND CONSTRUCTION OF THE CONTINUOUS DISINTEGRATOR AND ACCESSORY EQUIPMENT

Introduction

In all the previous experiments the explosion process was carried out in batch operations. A charge of 200 or 400 g of cossettes was placed in the pressure chamber and, after steaming at atmospheric pressure, blown out against an impact baffle by a sudden increase of steam pressure. This arrangement had a great experimental advantage in that it required only a small amount of beet for one test, so that a number of runs could be made in one day from the same sample of cossettes. This permitted the determination of the influence of the process conditions on the purity of the juice, eliminating the influence of the quality of the beet. The slicing and mixing of cossettes was done quickly by hand.

However, from the viewpoint of commercial use this equipment had some serious disadvantages. During the explosion in the batch equipment, about 1 lb of cossettes in the form of a slug was blown out against the baffle in a time of less than 1 second. It is believed that, as a result of the loss of momentum at the impact and as a result of the small exposed surface of the baffle, only a part of the cossettes had a chance to strike the bare surface of the baffle, the rest being prevented from doing so by the pulp already formed but not yet removed from the baffle. In the preliminary recovery tests (Progress Report III) this harmful effect had been only partially decreased by using a concave baffle with a distributing cone in the center.

Another disadvantage of the batch explosion equipment was its great weight as compared with the weight of the sample. This resulted in greater heat losses due to convection, radiation, and warming up of the equipment. The amount of condensate formed during steaming was therefore much in excess of that corresponding to the heating of cossettes, causing unnecessary dilution of the juice. Another drawback of the batch system was the difficulty of regulating the duration of the explosion process.

The batch equipment had served its purpose by providing valuable information concerning the quality of the juice and the recovery of sugar. However, a further study of the process and of its commercial feasibility required a more flexible piece of equipment in which the optimum process conditions could be determined.

It was therefore decided to design and construct a continuous disintegrator flexible enough to allow study of the steam economy of the process and of the optimum conditions for good sugar recovery. Simplicity of construction, low cost, and ease of operation have also been considered, so that if the results prove successful the equipment could be used as a model for larger-scale equipment.

Flow Sheet of the Experimental Plant

Before the details of design are discussed, the flow sheet of the experimental assembly is given with a brief explanation of the experimental procedure.

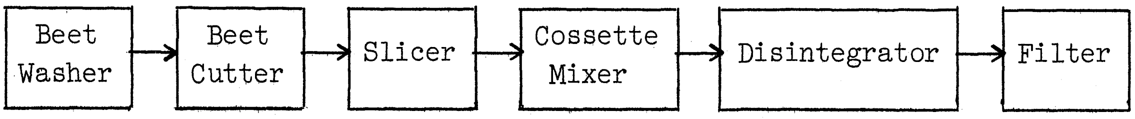


Fig. 1. Flow Sheet of the Experimental Plant

A sample of about 100 lb of beet is first washed in the beet washer (see Fig. 1) to remove the adhering dirt and then passed to the beet cutter. In the beet cutter each beet is first cut with a pair of knives to the same length and then a number of incisions are made in the direction perpendicular to the long axis of the beet. The distance between the incisions determines the length of the cossettes. Each beet is then transferred separately to the slicer, where it is sliced to cossettes of the required thickness. After slicing, the cossettes are placed in a drum mixer and mixed well to obtain a uniform sample of 25 to 50 lb of cossettes.

A part of the sample is used for the determination of sugar and preparation of the diffusion juice which is to be used as a standard of comparison; the rest is transferred to the feeding device of the disintegrator. The pulp obtained from the continuous disintegrator is then charged into the filter (or centrifuge) and the juice separated.

The draft, the amount of cake, and its sugar content, as well as the amount of wash water used, are determined. The purity of the juice is compared with that of the diffusion or hot digestion juice prepared from the same sample. Once the optimum working conditions have been determined, both the "explosion" and diffusion juices are subjected to a standard purification process (see Progress Report III) and the quality of the resulting thin juices compared.

General Description of the Equipment

Beet Washer. As beet washer, a rectangular tank 20 by 24 by 20 inches will be used. The tank is provided with a steam coil and a separatory screen. The beets will first be washed in warm water and then rinsed with a spray of cold water to knock off loose dirt.

The Beet Cutter. There are two important reasons why the beet particles should be of a uniform and comparatively small length: First, the preparation of a uniform sample in the cossette mixer will be much easier and more reliable. This point cannot be overemphasized, since the diffusion juice will be prepared from the same sample and used as a standard of comparison. Another reason is that the disintegrator pipes are designed for diameters ranging from 3/4 to 1/2 inch. The use of greater diameters would call for very high processing capacities, too great for experimental purposes. To diminish the possibility of choking the pipes, the length of cossettes should not exceed the diameter of the pipes.

In order to prepare cossettes of approximately equal length, the beet is first placed in front of the beet cutter (Drawing 1, Side A), the position of the knife reversed, and another knife slid on the knife shaft. The knives are then kept the desired distance apart as the head and a part of the tail of the beet are cut off by pressing the knives downward. When all the beets have been cut to the same length (6 inches), one knife is removed from the shaft and the other returned to its previous position as shown in Drawing 1.

The beets are then placed in the cutter box B and a number of incisions made. To insure equal distances between the incisions, a brass plate provided with a number of slots is mounted in the middle of the cutter. The slots are 1/2 inch apart and act as guides for the knife. A small portion (the bottom part) of the beet is left uncut so that after removal of the beet from the cutter the slices will be held together by the uncut portion.

A similar procedure was used in our previous work and is described in Progress Report II. In this cutter, however, only one incision was made at a time. The use of a number of knives would considerably speed up the cutting but might partially damage the slices by compression equal to the sum of the knife thicknesses.

The Beet Slicer (Drawings 2, 3, 4, and 5). After the incisions have been made, the beet is transferred to the slicer. The beet slicer consists of a steel plate (Drawing 4) with a smoothly finished upper surface. A rectangular hole is cut out in the plate to accommodate a regular slicer knife 165 mm long. The knife is set easily by means of a pair of set-screws and aluminum strips of different thicknesses. Any irregularity at the line of contact between the knife and the upper surface of the plate can be filled in with Wood's metal to insure a smooth upper surface (see Progress Report II, page 1).

A wooden box (not shown in the drawing) is firmly mounted above the plate of the slicer. The length of the box corresponds to the length of the beet, so that the beet fits tightly into the box. The beet is placed in the box with the incised part downward and slightly pressed with a wooden stamp against the reciprocating plate. After the incised part of the beet has been sliced off the slicer is stopped, the small uncut portion of the beet removed, and the next beet placed in the box. In this way all the beets are sliced one by one, which decreases the possibility of any sidewise motion of the beet. When a number of beets are sliced at a time, a certain shifting of the beets would be unavoidable and the uniformity of particles would be affected. It has already been mentioned that due to the small dimensions of the experimental disintegrator the particles should be small and as uniform as possible. In a large-scale installation this problem will obviously lose much of its importance.

The slicer was designed for 100 strokes per minute, and for a length of stroke of 12 inches. Only half of the stroke (6 inches) is used for slicing, in order to avoid greater changes in the linear velocity of the knife. The mean velocity of the knife when slicing the beet is about 5 ft/sec. The use of different types of knives will permit preparation of particles of different shapes and thicknesses.

The Cossette Mixer (Drawing 6). The purpose of the mixer is to prepare a uniform sample of cossettes of 25-50 lb. It has already been mentioned that this sample will be used not only for the explosion test but also for the preparation of reference juices and for the determination of sugar content in the beet. Good uniformity of the sample is therefore imperative. The idea of the design was to effect good mixing of the comparatively sticky particles without damaging them.

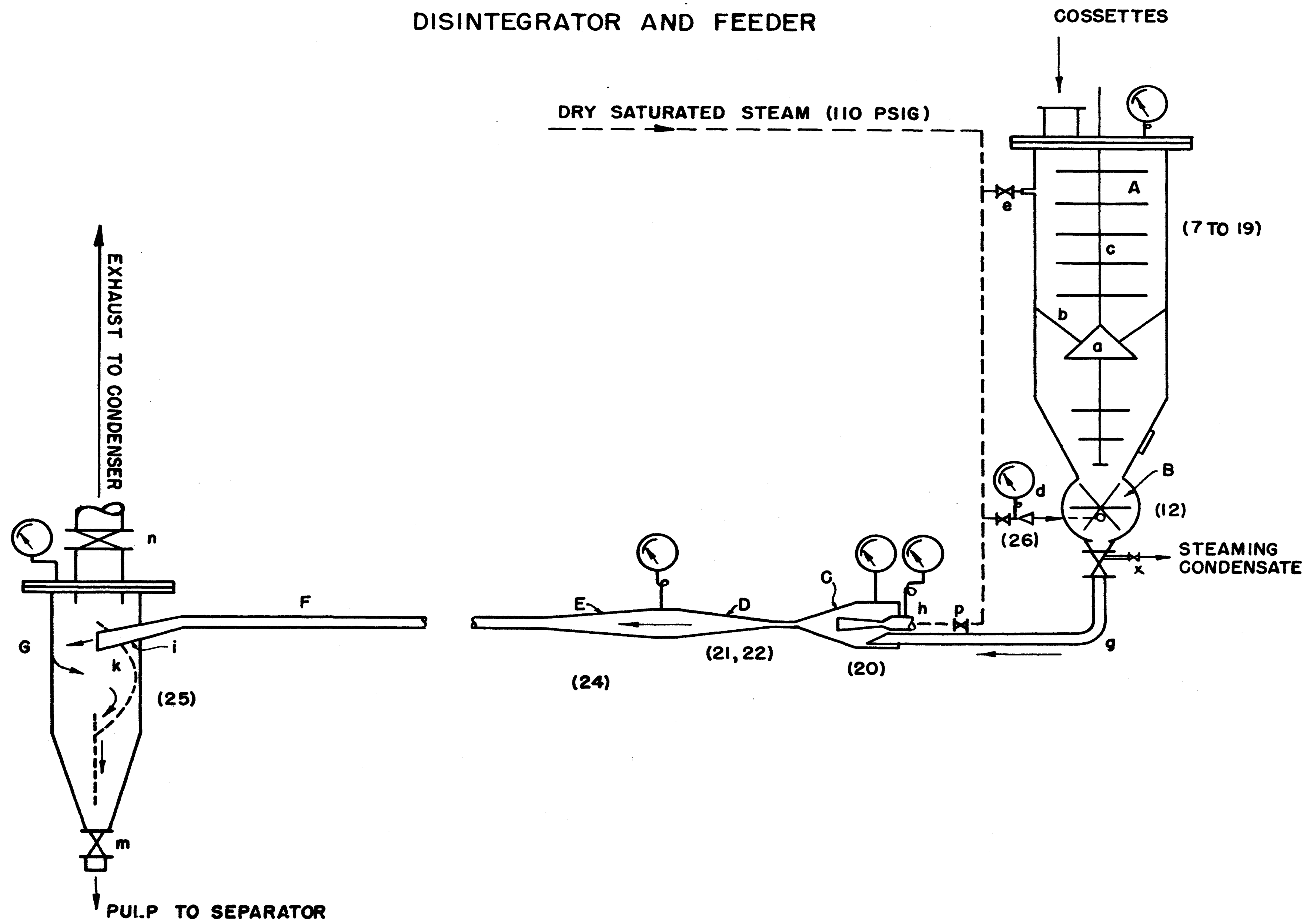
For this purpose a tumbling type of mixer is used. It consists of a slowly revolving (10 to 20 rpm) vertical brass cylinder 30 inches long and 14 inches I.D. with a removable cover at one end. To insure better mixing, the cylinder is provided with six rods running across the cylinder along a helical line. About one-third of the mixer is filled with cossettes (about 27 lb of cossettes), the cover closed, and the mixer revolved for 3 to 5 minutes. It is believed that this length of time will be sufficient to obtain a uniform mixture of cossettes. A portion of the mixed sample will be used for preparation of reference juice and the rest (about 25 lb) used for the experiment.

The Disintegrator. The disintegrator forms the main part of the experimental equipment and will therefore be described in detail later in this report. The purpose of this equipment is to disintegrate the beet to such a degree of subdivision that the juice can be removed easily by centrifuging or filtering followed by washing. The idea of this equipment is to accelerate beet slices (cossettes or particles of other shape) to a high velocity by use of expanding steam and to rupture the beet cells by impact of the steamed cossettes against a baffle to create a sudden change of momentum. In commercial operation, a portion of the expanded steam leaving the disintegrator can be recompressed and used again, and the rest can be used as heating steam. The flow sheet of this equipment is presented as Fig. 2 and the details in Drawings 7 to 29. The figures in brackets on the flow sheet are the number of drawings of a given part of the disintegrator and feeder.

Before the details of construction are described, a brief explanation of the equipment and its operation might be helpful. About 25 lb of well mixed cossettes are charged into the feeder A through an opening in the cover, where they fill about half the space above the cone a. As soon as the feeder has been filled, the reciprocating stirrer c is set in motion. The purpose of the horizontal arms on the stirrer rod is to loosen the mass of cossettes, which, especially after steaming, have a tendency to stick together and form clumps. The cone a moves together with the stirrer. The cossettes fall to the lower conical part of the feeder, from which, through a large opening, they fill the rotary-paddle feeder B.

Saturated steam of about atmospheric pressure is introduced into the lower part of the feeder and the cossettes are carried away with the stream of steam to the ejector chamber C, where the pressure is below atmospheric. For the sake of simplicity, live steam from the steam main will be used for this purpose. A throttling valve and a metering nozzle d will permit measuring the amount of the induced steam. In the case of commercial installation, a part of the exhaust steam, instead of being passed into the condenser, can obviously be used as induced steam and the rest used for heating purposes (juice heaters, etc.). In case the cossettes are to be steam-treated, the saturated steam can be introduced through valve e and the steaming condensate removed through branch f, at the bottom of the feeder.

FIG. 2
DISINTEGRATOR AND FEEDER



The cossettes carried away from the rotary feeder by the stream of low-pressure steam are then introduced through a 1-inch brass pipe into the ejector chamber C. Steam issuing from the nozzle h with a very high velocity transfers some of its momentum to the mixture which enters the chamber through pipe g, owing to the low pressure created by the action of the high-velocity stream. In the diffuser D the mixed vapor is recompressed, the work of compression resulting from the conversion of the kinetic energy of the steam. From the diffuser D the mixture passes through the diffuser tail pipe into a 3/4-inch brass pipe where the particles undergo further acceleration. The particles, moving at high velocity, enter the cylindrical baffle G tangentially through the inclined inlet nozzle i. The pulp obtained by the sudden change of momentum is carried downward along a helical partition k to the conical bottom of the baffle and removed through valve m. The separated expanded steam escapes through valve n and can be partially recycled through the rotary feeder or, as in the experimental arrangement, passed to a condenser. The pressure in the baffle space is to be kept slightly above atmospheric to facilitate the discharge of the pulp. The steam nozzles k and d are used as critical flow meters to measure the amount of the ejector and induced steam.

The pressure at different points of the installation will be measured by tested pressure gauges. The regulation of the flow of cossettes is described in the paragraph dealing with the feeder. To facilitate operation and supervision, the equipment was arranged horizontally. It is believed, however, that a vertical position would have been better, especially since the 90° elbow between the feeder and ejector chamber might thereby have been avoided and a straight path of travel obtained, but local conditions made it difficult to install apparatus about 25 feet long vertically.

The Separator (Drawing 30). In the previous experiments, described in earlier reports, a laboratory centrifuge was used for separating the juice from the cake. From the experimental point of view it presents, however, certain difficulties. First, it is difficult to obtain in a small centrifuge a layer of cake of uniform thickness, and second, the washing of the cake with one small spray nozzle is far from uniform.

To avoid these disadvantages, a filter has been constructed. It consists of two parts separated by a perforated brass plate covered with a heavy screen and filtering cloth. A known weight of pulp is charged into the upper vessel and spread uniformly with a wooden stamp of the diameter of the vessel. The filtered juice is collected in a brass-sheet container placed in the lower part of the separator. The upper cover and fittings make it possible to use the separator as a vacuum or pressure filter.

Detailed Description of the Disintegrator

In the following part of the report the design and operation of the essential parts of the disintegrator are described and the attached drawings explained.

The Feeding Device (Drawings 7-11 and 13-19). The purpose of the feeder is to obtain a constant and uniform rate of flow of the particles so that the ejector can be uniformly and continuously charged without appreciable pulsation in the rate of flow. This point is of special importance due to the small cross sections of the conduits in the experimental plant and the consequent danger of choking. Increasing the dimensions of the disintegrator pipe and diffuser was impracticable, as that would require a capacity too great for laboratory conditions. This problem, although of lesser importance in a large-scale installation, is of great importance in a small-scale plant. It has already been mentioned that in the case of steam pretreatment of cossettes the danger of the particles sticking together will be much greater than in the case of cold disintegration. As this equipment was designed to study both cases, special provision had to be made to avoid or decrease the formation of clumps. In addition to this main purpose, the feeder may be used as a cooker in case steam treatment should prove necessary.

The feeder consists of three parts made of bronze. The upper cylindrical part, 12 inches in diameter, can easily accommodate the 25 lb of cossettes used for one experiment. The use of greater amounts of beet for one experiment would call for more expensive and bulky accessory equipment. A smaller amount of cossettes would, on the other hand, make the time of the experiment too short. The bottom of the upper part consists of a system of two cones. The outside cone b (Fig. 2) is made of stainless-steel screen to allow the passage of condensate in the case of steam pretreatment. The inside cone a (Fig. 2) can be lowered to close the upper compartment and thus isolate it from the lower part of the feeder. If the cossettes are to be steamed before the disintegration, atmospheric-pressure steam is introduced through e (Fig. 2) and the sugar-containing condensate together with excess steam removed through the screen b and pipe f. A small valve at the top of the cover (Drawing 8) insures the necessary venting of the upper compartment.

A vertical stirrer is mounted in the feeder to loosen the clumps of particles and to effect a uniform discharge from the upper compartment (see Fig. 2 and Drawings 13-18). A number of horizontal paddles and the closing cone a are mounted on the stirrer rod. Driven by an electric motor and a crank disk, the stirrer makes a reciprocating motion up and down. The length of stroke as well as the number of strokes per minute can be regulated. As the closing cone a is fixed on the stirrer rod, this arrangement allows also an approximate regulation of the rate of discharge of cossettes from the upper chamber to the conical part which forms the hopper of the rotary feeder. The lower part of the stirrer, which reaches almost to the bottom of the cone, keeps the cossettes in constant motion to allow a uniform filling of the rotary feeder.

A sight glass provided in the conical part of the feeder (Drawing 11) permits control of the amount of cossettes in the hopper. The hopper is to be kept partially full at all times to prevent the rotary feeder from running empty.

As the purpose of the upper compartment is to loosen the mass of particles, the purpose of the rotary feeder (Fig. 2, B, and Drawing 12) is to obtain a uniform rate of particle flow. The cylindrical casing of the feeder is 2-1/2 feet wide and 6-5/8 inches in diameter. An impeller with six blades is mounted inside the casing. The rotary feeder is charged from the hopper through an opening 2 by 3 inches cut out in the upper part of the casing. The cossettes moved by the rotating blades are carried to the bottom of the feeder, where they meet a stream of the induced steam introduced through a 3/4-inch brass pipe mounted in the front plate of the feeder. Due to the vacuum existing in the ejector chamber, the cossetts are carried away from the feeder through a 1-1/2-inch gate valve into the discharge pipe. The valve is always left open except during the period of steaming. The speed of the impeller can be regulated within wide limits by a speed reducer. However, in order to reduce the action of the centrifugal force, which might interfere with charging the impeller, the dimensions of the casing are so designed as to give a rate of flow of about 25 lb/min at 25-30 rpm.

It may be expected that when a given impeller compartment reaches the stream of the induced steam, all the cossettes it carries will be removed before the next compartment meets the stream. This would result in pulsations of flow occurring approximately every 1/3 sec. This pulsation is apt to cause considerable disturbances in the working of this small-scale equipment. It must be borne in mind that, due to the high velocity, the particle will stay in the disintegrator for only a fraction of a second. Thus pulsation of flow would result in the disintegrator alternatively running empty and being overcharged. In the latter case the diffuser throat or other parts of the equipment may be choked up with cossettes and the flow stopped altogether. The disadvantage of overloading the baffle has already been discussed in Progress Report III (page 29). To decrease the pulsation of flow, a round orifice (Drawing 12) is introduced into the outlet opening of the rotary feeder and the velocity of the impeller slightly increased above that corresponding to the desired feed rate. In this way there will always be a certain amount of cossettes left in the compartment and the danger of "empty periods" will be avoided. It is believed that this simple device will help to achieve the necessary uniformity of flow.

In case choking occurs at the entrance to the rotary feeder, compressed air will be introduced at the base of the cone (see Drawing 12, a) to loosen the cossettes. To remove the air, a free space of about 1/4 inch will be left between the flanges of the upper and the middle compartment of the feeder.

The mixture of steam and cossettes leaving the rotary feeder enters a 1-1/2-inch brass pipe bent at 90° (the radius of the bend is 6 inches) and is introduced through a reducing adapter into a 1-inch brass pipe leading to the ejector chamber (see Fig. 2 and Drawing 20). The 1-inch inlet pipe consists of a number of short pipe lengths machine-threaded on both ends and connected by couplings. This type of joint makes it possible to bring the ends of pipes together and thus give a smooth and uniform inside surface to the inlet pipe. As the cossettes undergo acceleration in the inlet pipe, this arrangement will make it possible to adjust the length of pipe to obtain the required inlet velocity of cossettes.

The Ejector Chamber (Fig. 2, C, and Drawing 20). In the ejector chamber the steam issuing from the nozzle transfers some of its momentum to the mixture of vapor and cossettes which enters the chamber owing to the vacuum created by the high-velocity stream. The chamber consists of a cylindrical part 4-1/2 inches I.D. and 2 inches long and a conical part 5-5/8 inches long. The whole chamber is made of one piece of bronze and is smoothly machined inside. In the cover fixed on the cylindrical part are two openings, the central one for the steam nozzle and the other for the steam-cossette mixture. Both the inlets are threaded outside so that they can be adjusted to the desired length inside the chamber.

The conical part has a total angle of convergence of 30°. Therefore, the cossettes when passing through the chamber will undergo two 15° deflections, one on the wall of the cone and another in front of the steam nozzle. This deflection could be decreased slightly by decreasing the angel of convergence of the cone, but this would require a very long ejector chamber.

There are several possible ways to decrease or avoid the change of direction of the flow of cossettes, but unfortunately they present serious constructional difficulties when applied to small-scale equipment. One possibility is the use of an annular nozzle instead of the usual nozzle and the introduction of the cossettes through the centerline of the nozzle. For an annular nozzle of 2-inch diameter and having the same cross-sectional area of the throat as the nozzle shown in Drawing 20, the width of the annulus would be only 0.005 inch. This idea was discarded because of the difficulty in construction and ease of damage and wear to an annulus of such close tolerance. The use of a ring of small separate nozzles, although easier to fabricate, presented similar constructional difficulties.

A safety valve is mounted on the cylindrical part of the chamber (left side of Drawing 20) to release the pressure in case the diffuser throat or the disintegrator pipe becomes choked with cossettes.

The Ejector Nozzle (Drawings 20 and 23). The convergent-divergent nozzle shown in Drawing 20 was calculated by a method of Emswiller and Schwartz. The conditions of operation and the dimensions are given below:

1) Injector-steam pressure	125 psia
2) Pressure in the chamber	12 psia
3) Injector steam rate	0.055 lb/sec
4) Ratio of induced to injector steam	0.41
5) Diameter of the throat	0.200 in.
6) Diameter of the exit	0.317 in.
7) Exit velocity	2.660 ft/sec
8) Efficiency of the nozzle, assumed	0.96
9) Pressure at the diffuser outlet	27 psia

The value of 0.055 lb/sec for the injector steam rate needs more detailed explanation, since it depends on the design of other parts of the equipment. At the time when this equipment was designed, the final velocity of the cossettes needed to produce a good disintegration on impact at the baffle was unknown, and a certain value therefore had to be assumed. The experimental data on pneumatic grain transporters, although helpful in other respects, are of little value as far as this point is concerned. The velocities used in grain transportation are low to avoid damage to the grain; G. Segler in his book on pneumatic grain conveying[2] points out that velocities higher than 35 ft/sec may cause considerable damage to grain during its passage through the conduit. It is certainly to be expected that a beet particle, with its weaker mechanical structure and very high moisture content, should be more easily disintegrated than grain, especially when an impact baffle is used. Furthermore, after disintegration the pulp formed on the baffle would have a tendency to stick to the surface and build up a layer which would "insulate" the baffle surface and decrease the efficiency of the process. It seems necessary, therefore, to use such a value of the final velocity of particles that after disintegration the pulp formed could be removed quickly from the baffle. Obviously, a certain accumulation of pulp on the baffle due to the loss of momentum is unavoidable. It was assumed as a first approximation that a final velocity of 200 ft/sec would be enough to disintegrate the particles and carry away the pulp to the baffle outlet. This point will be discussed further in the paragraph dealing with the design of the baffle.

We know from the work of Cramp and Priestley[3] and Wood and Bailey[4] and the recent work of Newitt et al.[5] that when a particle is accelerated, it is not traveling at the same velocity as the conveying air but slower: there is a definite slip past the solid particle, so that the solid particle never attains the velocity of the surrounding gaseous medium. Moreover, the particles are continually losing energy by collisions among themselves and with the walls of the pipe. From the experimental data published by Cramp and Priestley[3] it can be seen that the final velocity of grain moving in a pipe 27 ft long* was about 55 percent of the velocity of the air, with a tendency to increase with higher air velocities. Higher values have been obtained by Newitt[5] in his experiments.

However, it must be pointed out that these values, apart from other factors, depend on the shape and size of particles and on the roughness of the pipe wall. In this design it was assumed that for a pipe length greater than the length of the main region of acceleration, a final steam velocity of about 300 ft/sec will be necessary to accelerate the cossettes to 200 ft/sec. Taking the same outlet conditions of steam and the same feed rate of cossettes, the amount of steam used per weight of beet will now depend only on the cross section of the disintegrator pipe. Small pipe will decrease the amount of steam required but increase the pressure drop and the danger of choking. The reverse will be true for the case of a larger-diameter pipe. It has already been mentioned that in this small-scale installation the use of pipe diameters smaller than the length of particles might prove dangerous due to the possibility of choking. It was therefore decided to start the experiments with 3/4-inch pipe (I.D., 0.822 inch) but provide at the same time for the use of 1/2-inch and 1-inch pipes by special adapters.

For the outlet steam conditions of 0 psig (saturated), the rate of flow of the steam through a 3/4-inch pipe will be 2.64 lb/min (0.044 lb/sec) at the outlet velocity of 320 ft/sec. For the feed rate of cossettes of 26.4 lb/min (design capacity of feeder, about 25 lb/min), the amount of steam will be 10 lb/100 lb of cossettes. In this calculation, the decrease of the free cross-sectional area caused by the presence of cossettes has been neglected. It will be shown later that the ratio of the volume of cosettes to that of the motivating steam is very small.

As a certain condensation of steam resulting from the contact with cossettes (see the paragraph dealing with the disintegrator pipe) cannot be avoided, the value of the steam rate, 0.044 lb/sec, has been increased to 0.055 lb/sec to be used for the design of the ejector nozzle.

The nozzle presented in Drawing 20, as well as the spare nozzle (Drawing 23), will also be used as critical flow meters.[6] For this purpose

*The air velocity at the end of the pipe was 100 to 120 ft/sec.

a pressure gauge will be mounted 3 inches upstream from the throat of the nozzle (not shown on the drawings). With the help of the throttle valve p (Fig. 2) the steam pressure corresponding to the required rate of steam flow can be adjusted easily. This arrangement permits simple regulation of the rate of flow of injector steam as well as of the induced steam (see Drawing 26).

The Diffuser. The purpose of the diffuser is to compress the mixed vapor to obtain a steam pressure for the pressure gradient needed to accelerate the cossettes and to overcome friction in the disintegrator pipe. The duration of contact between cossettes and steam at this pressure will be short unless the diffuser is extended for a considerable length. If a short diffuser is used, the cell rupture will be caused primarily by impact rather than by inflation. The work of compression in the diffuser results from the conversion of kinetic energy to pressure energy. The diffuser was designed on the basis of Elrod's method[7]. The calculation was made for the case of pure steam. Due to the lack of available data, the influence of the presence of solid particles has been neglected.

The diffuser presented in Drawing 21 was made from one piece of bronze. It consists of three parts: (1) the diffuser entrance through which the mixture enters the diffuser throat (this conical entry has an overall angle of convergence of 25°); (2) the diffuser throat which connects the diffuser entrance with the diverging part of the diffuser (this throat has parallel sides of a length four times the throat diameter, and for the conditions given above in the design of the steam nozzle the diameter of the throat is 0.500 inch and the velocity in the throat is 1260 ft/sec); and (3) the diverging part of the diffuser (which has a total angle of 10° and a length of 10 inches, and compresses the vapor mixture, at a ratio of induced to ejector steam of 0.41, to a pressure of 27 psia). Different conditions at the outlet of the diffuser can be obtained by changing the ejector steam pressure and the amount of the induced steam. Drawing 22 presents a spare diffuser of similar construction but of a larger throat diameter (0.75 inch).

The Diffuser Tail Pipe (Drawing 24). The purpose of the tail pipe is to connect the diffuser outlet with the disintegrator pipe. It is made of bronze and consists of a 2-inch-long cylindrical part and a conical end (10°) reducing the outlet diameter of the diffuser from 2 to 1.062 inches. It can be directly connected with a 1-inch pipe or by adapters with pipes of smaller diameters.

The Disintegrator Pipe. The purpose of the disintegrator pipe is to provide a necessary length of path for the acceleration of cossettes and to connect the diffuser with the baffle. It consists of a number of short pipe lengths connected by couplings in the same way as the inlet pipe was connected to the ejector chamber. It is supported (together with diffuser and ejector chamber) by four supports (see Drawing 27). A vertical slot in the upper part of the support permits the installation of the pipe at different heights above the floor, depending on what entrance to the baffle will be used in a given experiment (see description and design for the baffle).

Some of the important points concerning the disintegrator pipe have already been discussed in the paragraph on the ejector chamber. The cross section of the pipe, as well as of other parts of the equipment where the cossettes undergo acceleration, should not be small enough to cause excessive pressure drop or choking. The work of Cramp and Priestley[3] and of Newitt et al.[5] throws some light on the conditions existing in the pipe. In a horizontal conveying pipe the total energy expended must originate in the stream of motivating fluid. The total pressure drop in the conveying pipe can be separated into three parts: the pressure drop resulting from the frictional losses connected with the air or steam itself, that due to additional losses caused by the presence of solid particles, and the pressure drop resulting from a continuous transfer of energy from the motivating fluid to the particles in order to accelerate them and compensate for energy losses caused by collisions of particles with each other and with the wall of the pipe. This problem has been studied extensively by Cramp and Priestley[3] and a number of formulae derived for the case of the vertical transportation of grain by a stream of air. But their research work, although helpful in our design, is not directly applicable to horizontal pipes. Even for the case of grain and vertical transportation, these formulae should not be expected to give accurate results for pipes much less than 27 ft long and air velocities greater than 120 ft/sec. Unfortunately the investigations recently carried out by Newitt et al.[5] on horizontal pneumatic conveying are still too incomplete to be of great help in our design.

As the velocity of particles is concerned, an interesting theoretical equation has been developed by Wood and Bailey.[4] It gives a relation between the air speed and the final speed attained by the particle in the pipe. According to this equation the length of the "initial acceleration" region, during which the particle approaches its final speed, is independent of the air speed, unless the coefficients of friction are affected by variations of the air speed. It does depend, however, on the shape and size of the particles and on the roughness of the pipe wall. But it must be stressed that the particles never reach equilibrium velocity, as the gaseous motivating medium is continuously accelerating due to the pressure drop in the system. Their experiments seem to confirm this equation. Using a horizontal pipe 2.9 inches in diameter, they found with sand and linseed that the pressure gradient which was very steep at the inlet became roughly constant at about 30 to 40 diameters from the inlet, in spite of different solid-to-air ratios and injector pressures.

In the design of the disintegrator, provision was made to allow for the extension of the disintegrator pipe up to 10 ft. On the basis of the above discussion, it seems that this length should be sufficient to cover the region of main acceleration, especially since the cossettes will already be partially accelerated in the inlet pipe and ejector chamber.

There is still another point which needs explanation, namely the condensation of the steam on cossettes between the feeder and the baffle. A certain condensation of steam cannot be avoided, especially when steam pretreatment is omitted and the cossettes are cold. The amount of condensation, apart from the temperature difference and physical characteristics of the cossettes, will depend on the surface area of the particle and on the time of contact. Therefore, the bigger the particle the greater its velocity, and the shorter the pipe the smaller will be the condensation. In calculation for the steam nozzle, the amount of steam needed for the process was increased by 25 percent on the basis of approximate calculation by Schmidt's method[8]. It seems, however, that the condensation will be much below this value.

The Baffle (Fig. 2 and Drawing 25). The main purpose of the baffle is to provide an efficient impact surface for the cossettes. In addition, it should allow for easy separation of the exhaust steam and continuous removal of the pulp.

It consists of an upper cylindrical part of 6-5/8-inch I.D. and an 8-inch-long conical bottom. The baffle, including the cover and inlets, is made entirely of bronze. Half of the inside circumference of the cylindrical part is covered with grooves which run vertically along the total height of the cylinder. A semicylindrical partition is mounted inside the cylindrical part at a distance of 1/2 inch from the grooved surface.

The cossettes accelerated in the disintegrator pipe are introduced into the baffle through a tangentially mounted inlet collar having a 10° inclination from the horizontal. The high-velocity particles impinge against the grooved portion of the cylinder and are carried along the wall up to the point where the grooved portion ends. The 10° inclination of the inlet collar brings the pulp to a level lower than that of the inlet. From the end of the grooved portion, the pulp is picked up by a helical partition and carried downward to the base of the cylinder and farther to the bottom of the cone, from which it is removed through a 2-inch gate valve. The pressure in the baffle zone is kept slightly above atmospheric to allow easier discharge of the pulp. The separated steam escapes through the opening in the cover of the baffle and is carried away to the condenser.

If the pulp leaving the grooved portion has sufficient residual velocity, the helical partition can be shortened to allow the pulp to make another turn through the grooved portion. If, on the other hand, the cossettes lose so much of their momentum during the passage through the grooves that their residual velocity is too small to carry the pulp downward, the lower baffle inlet is used. In case the energy of the particles is not enough to carry them along the total grooved surface, a part of the surface will be smoothed by filling up the grooves with soft solder or some other low-melting-point alloy. It is believed that these provisions will give the baffle sufficient flexibility of adjustment to obtain a good disintegration and at the same time easy discharge of the pulp.

It has already been stressed that the construction of the baffle should allow quick and easy removal of the pulp. There is still another important reason for this requirement: in the baffle space the pulp is in direct contact with saturated steam, and excessive condensation may occur if the pulp is not removed quickly from the baffle. This would result in dilution of the juice and in a higher draft.

In the following lines an attempt is made to illustrate the situation existing on the baffle surface. Imagine that the flow of cossettes close to the entrance of the baffle has approached steady conditions and the velocity of cossettes is 200 ft/sec. The weight of cossettes in the last 1-ft length of the pipe can be calculated with the help of the following formula:

$$M = \frac{F\,L}{V} ,$$

where L = length of pipe, ft;

F = feed rate, lb/sec;

V = velocity of cossettes, ft/sec; and

M = mass of material in L ft of pipe.

Substituting for F the design feed rate of 0.44 lb/sec and for V the velocity of 200 ft/sec and taking L = 1, we obtain the weight of cossettes per linear foot of pipe equal to 0.0022 lb (1.00 g). Assuming that the length of the cossettes is 454 ft/lb (30.5 m/100 g) and the length of one particle is 0.5 inch, there will be 24 particles in 1 ft of pipe.

These particles can be visualized traveling athwart at a distance of 0.5 inch. At a given moment, granting uniformity of flow, only one particle will emerge from the pipe outlet and strike the baffle. The cross section of the inlet is 2 by 0.5 inch and its projection on the inside wall of the baffle is about 4 square inches (for an arc 2 inches long and 2 inches high). Therefore each particle will have the chance to strike any place on this surface area.

Now assume that, due to the sudden loss of momentum at impact, the average velocity at which the particle will leave the projected area is 100 ft/sec. The average length of path the particle will have to travel to leave this area can be taken as equal to 1 inch (half the length of the arc). Therefore, at a velocity of 100 ft/sec the particle will leave the area in 1/1200 sec, since the particles strike the projected area at time intervals equal to 1/4800 sec, there will be, on the average, always 4 particles on this surface area, that is, 1 particle per square inch or 0.041 grams per square inch. If the weight of particles is doubled, the distance between the particles will be twice as great and at any moment there will be on the average 2 particles on the projected surface area; due, however, to the greater weight of the particles, the amount of cossettes in grams per square inch will be the same.

If, on the other hand, due to poor uniformity of flow, the particles travel as clumps at a large distance from one another, the baffle will be heavily overcharged at the moment of impact, as there will be little time left for the removal of the pulp. Gradually, as the pulp moves along the baffle, the velocity will drop and the amount of pulp on the baffle will be increased. It is expected, therefore, that favorable conditions at the inlet part of the baffle will be of the greatest importance.

The favorable action of the stream of steam should not be overlooked. It enters the space between the grooved surface and the semicylindrical partition with a velocity higher than that of the cossettes and should therefore decrease the accumulation of pulp on the surface at least in the space close to the inlet.

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1. J. Emswiller and F. Schwartz, Thermodynamics, 5th ed., McGraw-Hill Book Co., Inc., New York, 1943.

2. G. Segler, Pneumatic Grain Conveying, Braunschweig, 1951.

3. W. Cramp and A. Priestley, The Engineer, 137, 34, 64, 89, 112 (1924).

4. S. A. Wood and A. Bailey, Proc. Inst. Mech. Engrs., 142, 149 (1939).

5. R. H. Clark, D. E. Charles, J. F. Richardson, and D. M. Newitt, Trans. Inst. Chem. Engrs., 20, 209 (1952).

6. Fluid Meters, A.S.M.E. Research Publication, 1933 and 1937.

7. H. G. Elrod, "The Theory of Ejectors", Trans. A.S.M.E., 65, A-170 (1945).

8. E. Schmidt, Foppls Festschrift, Springer, Berlin, 1924.

APPENDIX

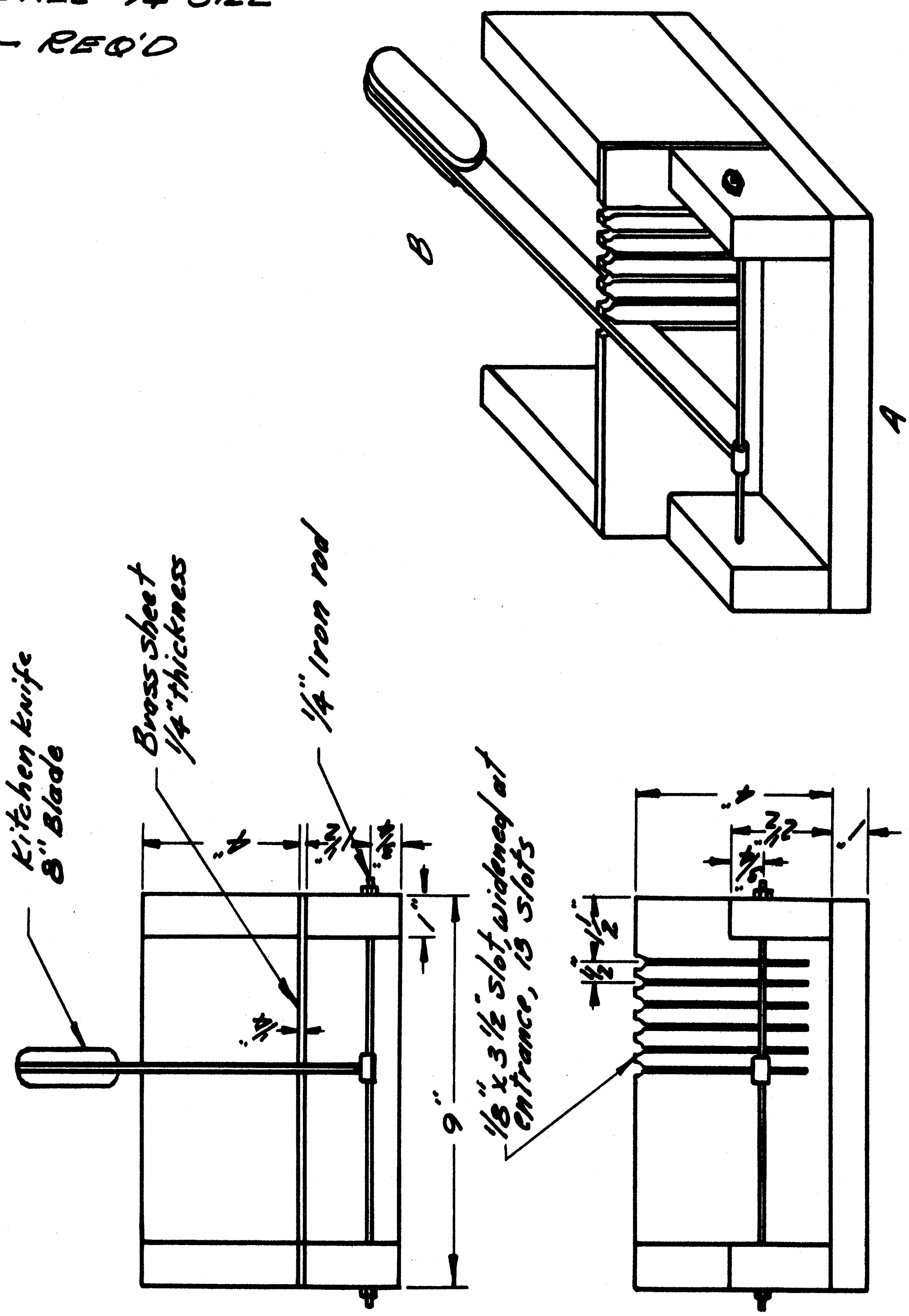
NO. 1

BEET CUTTER BOX

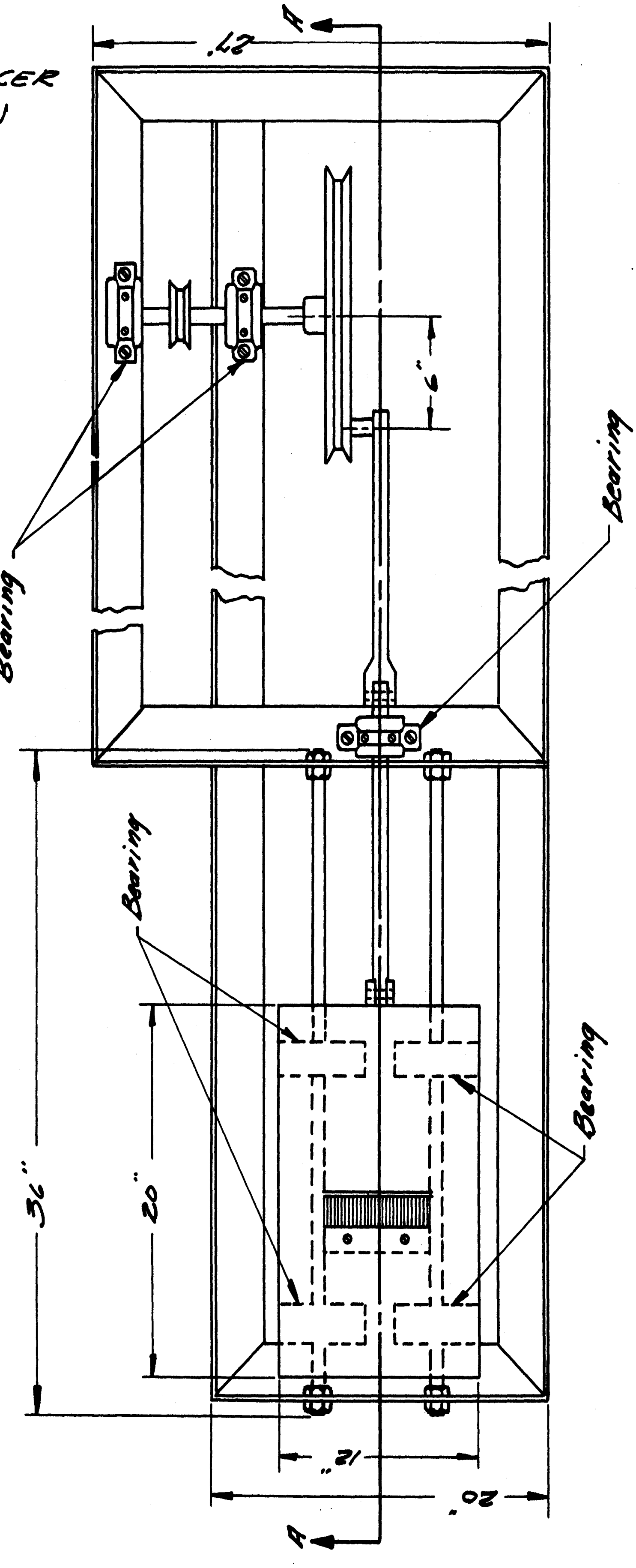
WOOD CONSTRUCTION

SCALE 1/4 SIZE

1 - REQ'D



No. 2
BEET SLICER
TOP VIEW

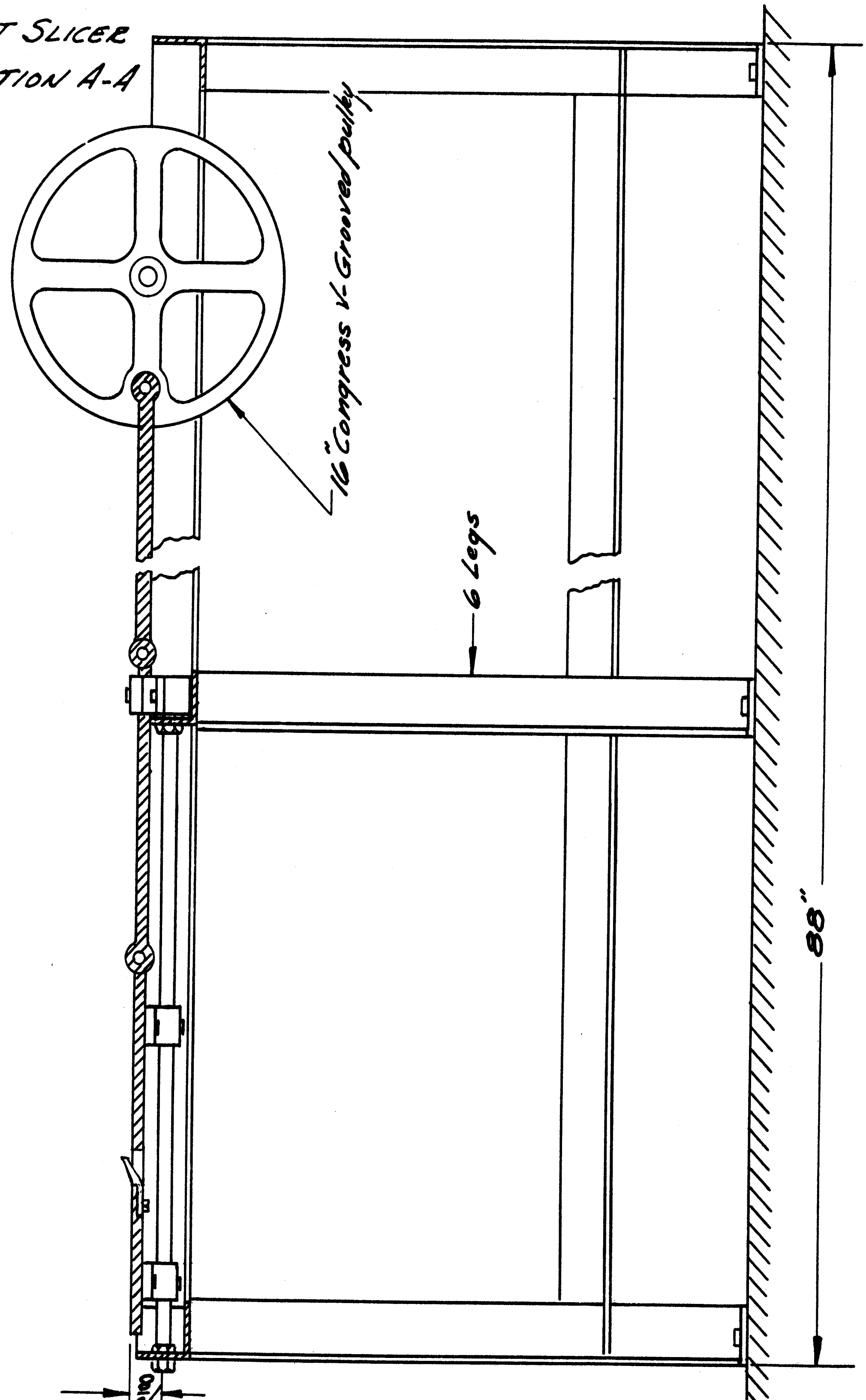


All Bearings: Boston cast iron pillow blocks with oilite bushing, cat. no. SRP12 for 3/4" shaft.
All Shafts: 3/4" Diameter
Frame: 3"x3"x1/4" Angle iron
Pulley: 16" Dia congress v-grooved pulley (Strelinger co.) for crank.
3" " " " " " driving
12" " " " " " motor

No. 3

BEET SLICER

SECTION A-A



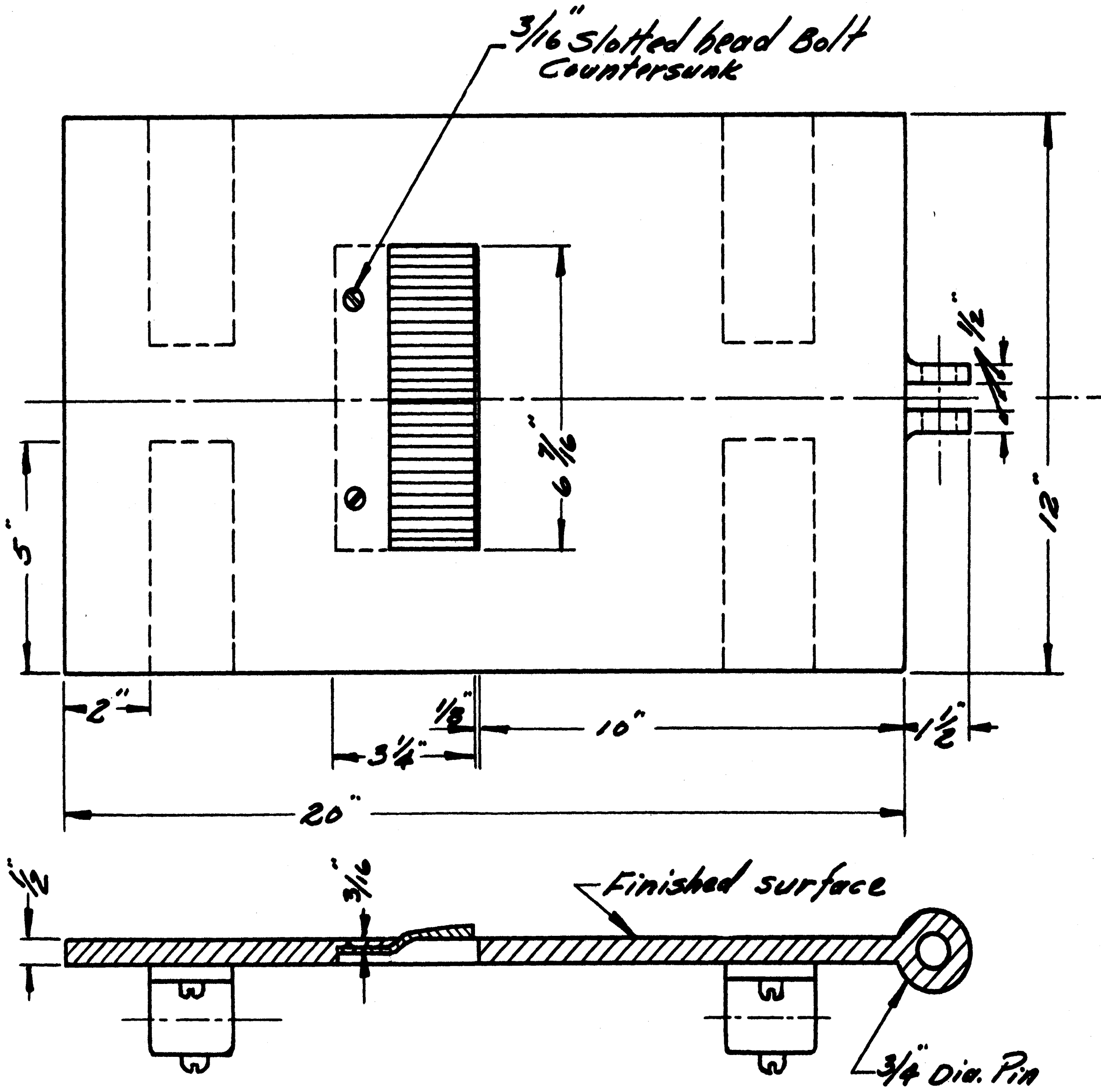
NO. 4

BEET SLICER KNIFE BOARD - DETAIL SKETCH

STEEL CONSTRUCTION

SCALE 1/4 SIZE

1 - REQ'D



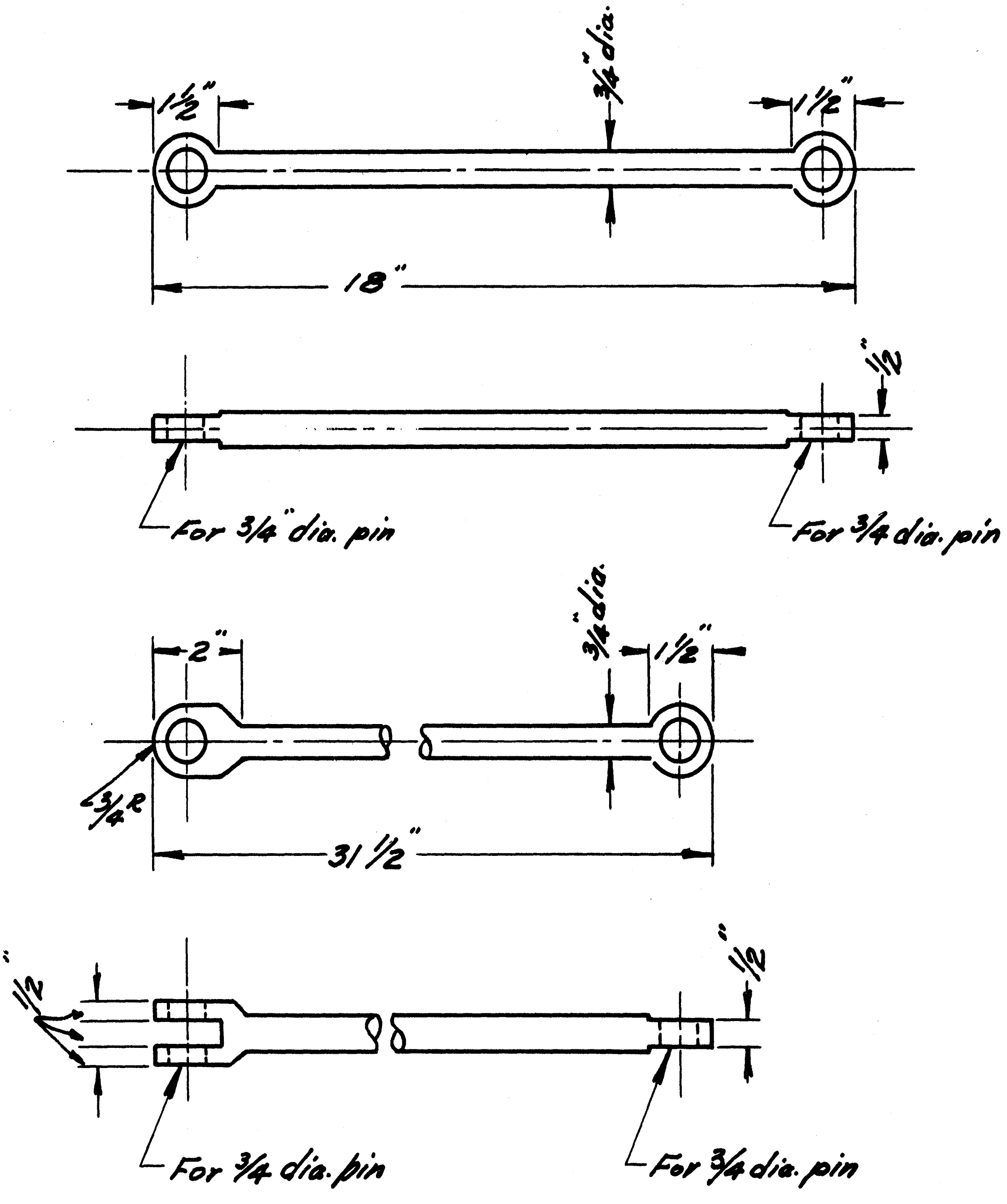
No. 5

BEET SLICER CONNECTING RODS - DETAIL SKETCH

STEEL CONSTRUCTION

SCALE - 1/4 SIZE

1 EACH - REQ'D

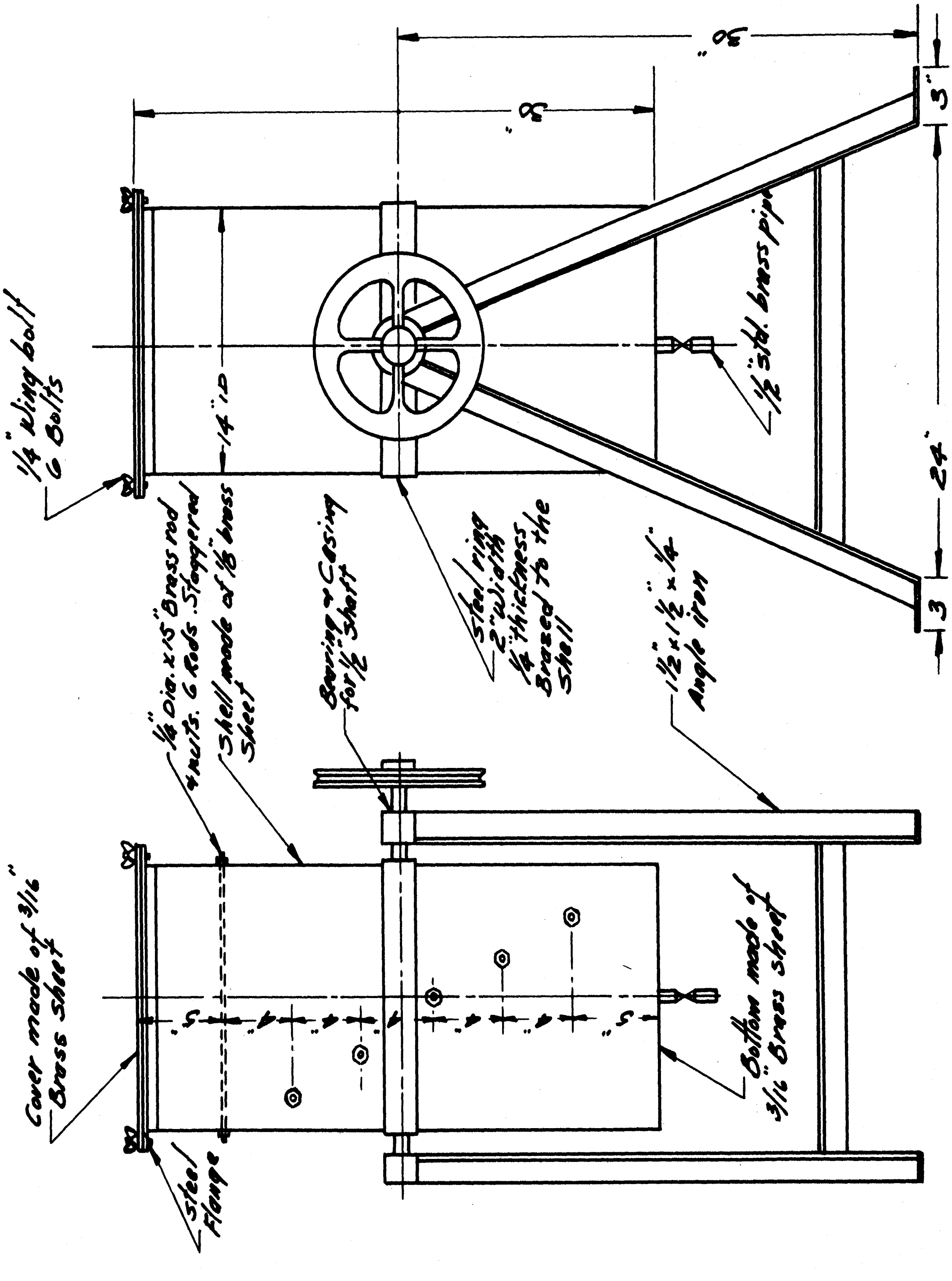


No. 6

COSSETTE MIXER & 1/2 HP MOTOR WITH REDUCING GEAR. SPEED 10-20 RPM.

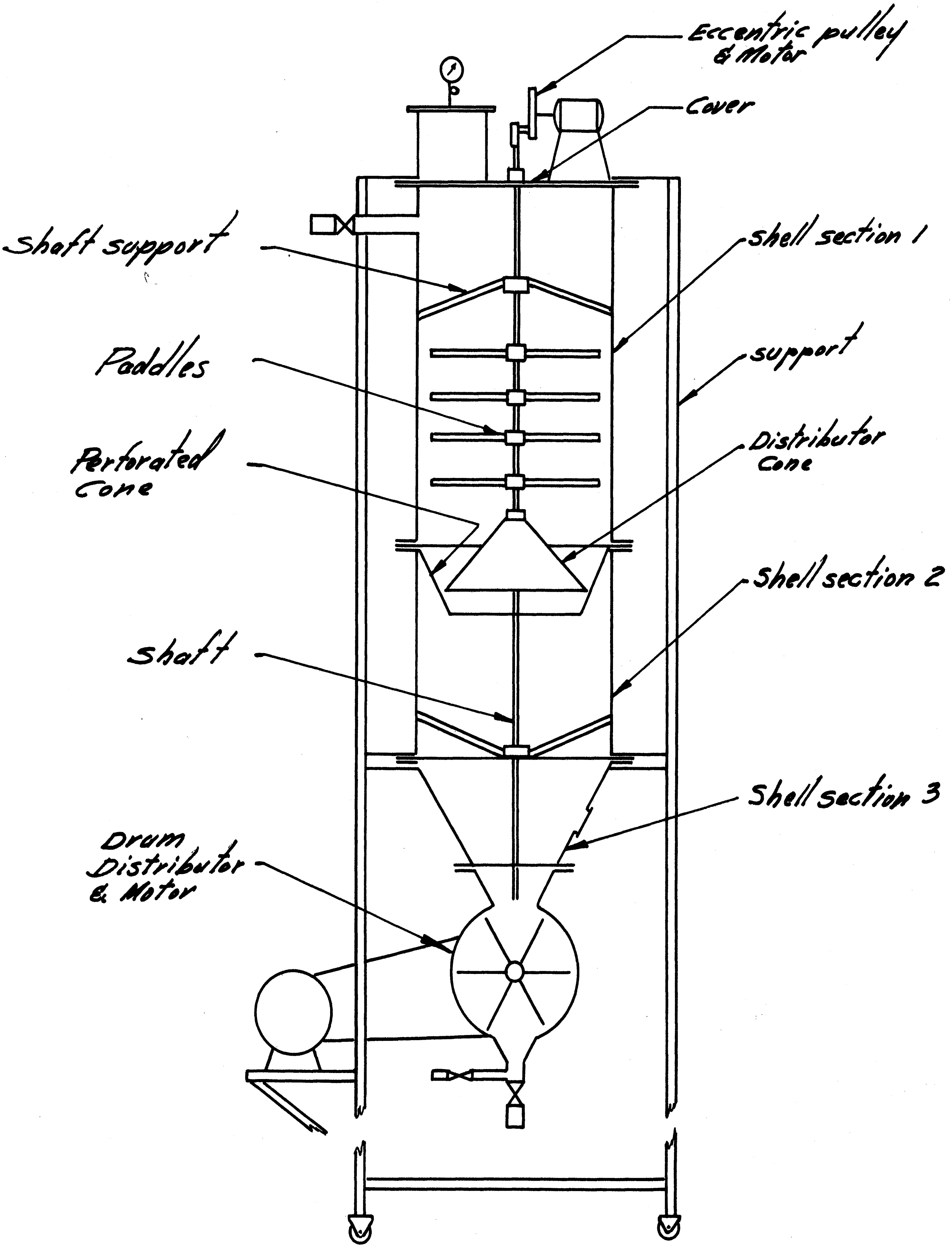
SCALE - 1/8 SIZE

1 REQ'D

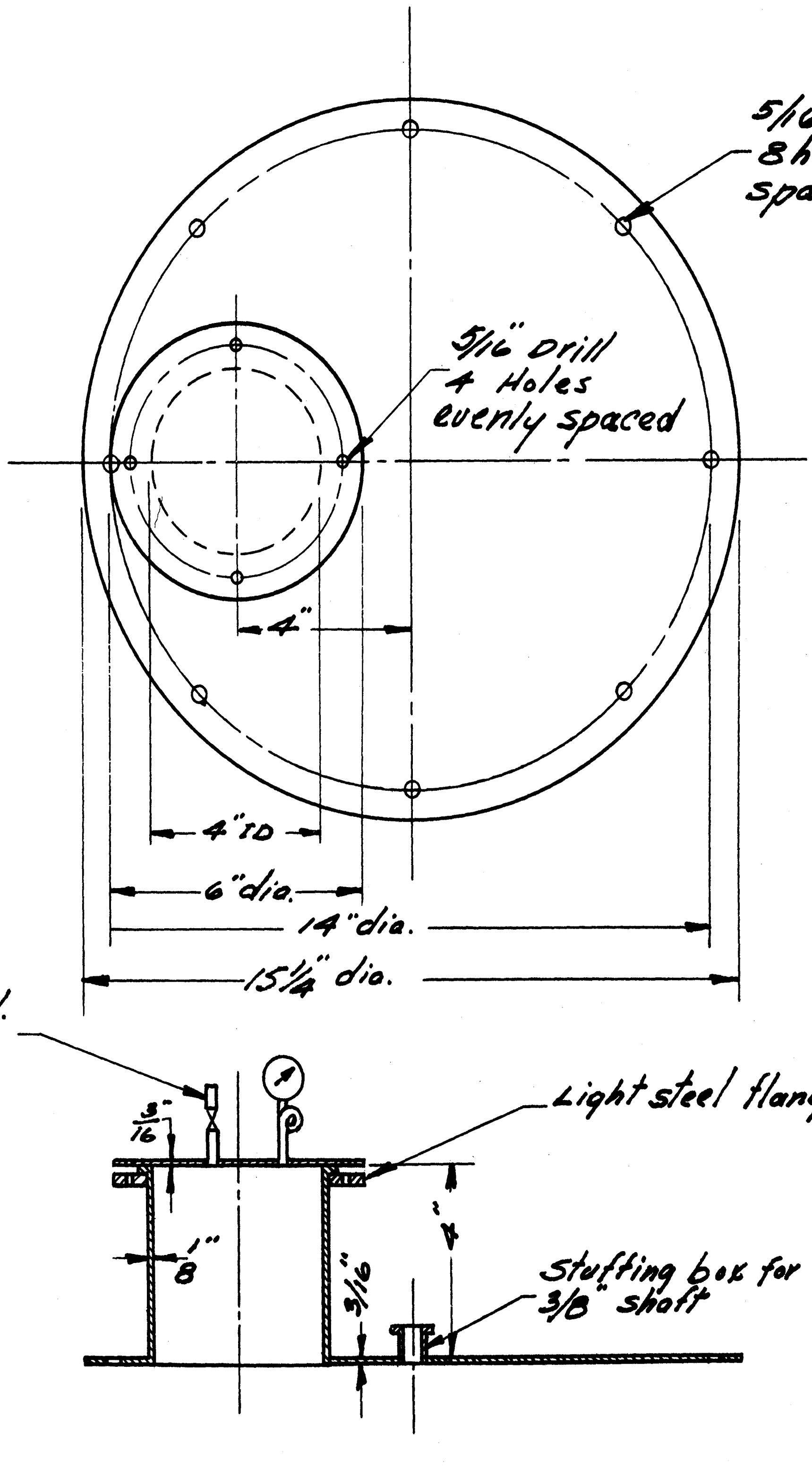


No. 7

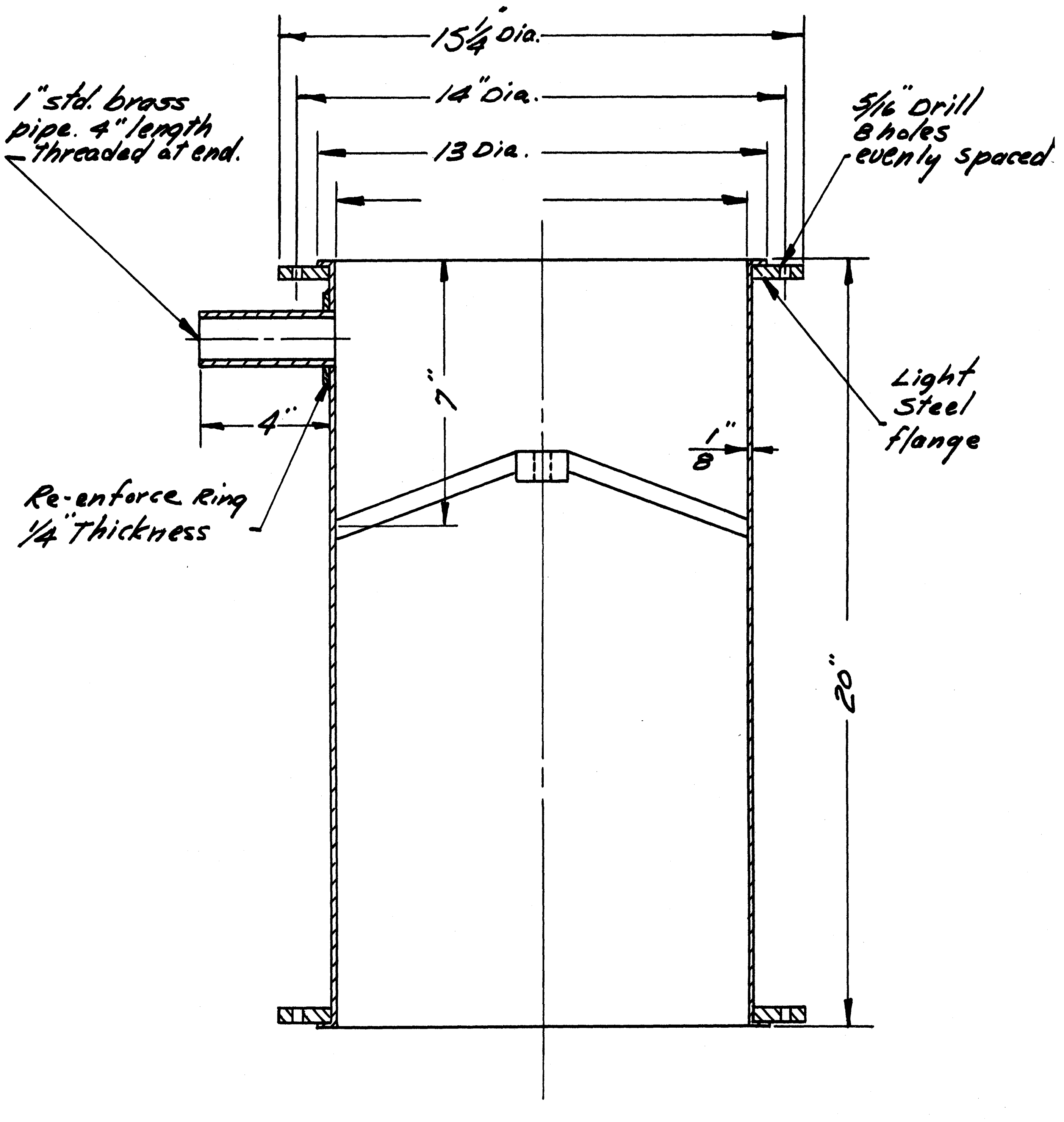
COSSETTE FEEDER ASSEMBLY SKETCH



No. 8
COVER - DETAIL SKETCH
BRASS CONSTRUCTION
SCALE - 1/4 SIZE
1 - REQ'D



NO. 9
SHELL SECTION 1- DETAIL SKETCH
BRASS CONSTRUCTION
SCALE - 1/4 SIZE
1- REQ'D



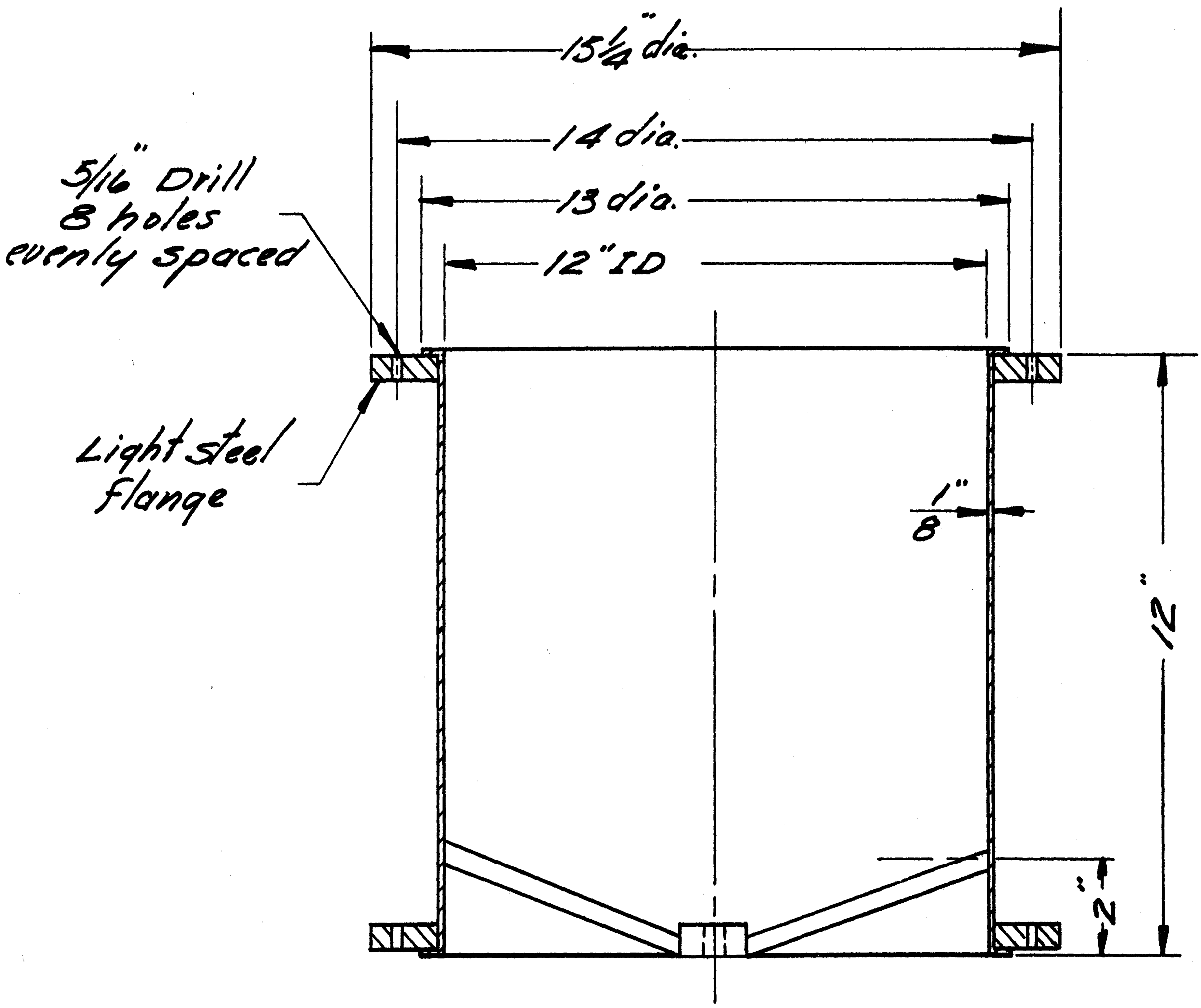
NO. 10

SHELL SECTION 2 - DETAIL SKETCH

BRASS CONSTRUCTION

SCALE - 1/4" SIZE

1 - REQ'D.



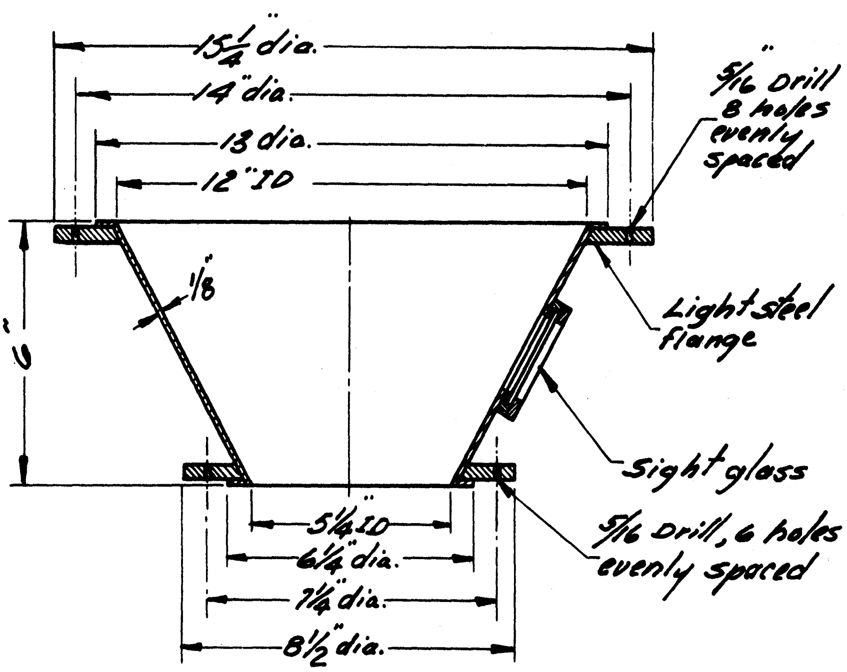
NO. 11

SHELL SECTION 3 - DETAIL SKETCH

BRASS CONSTRUCTION

SCALE-1/4 SIZE

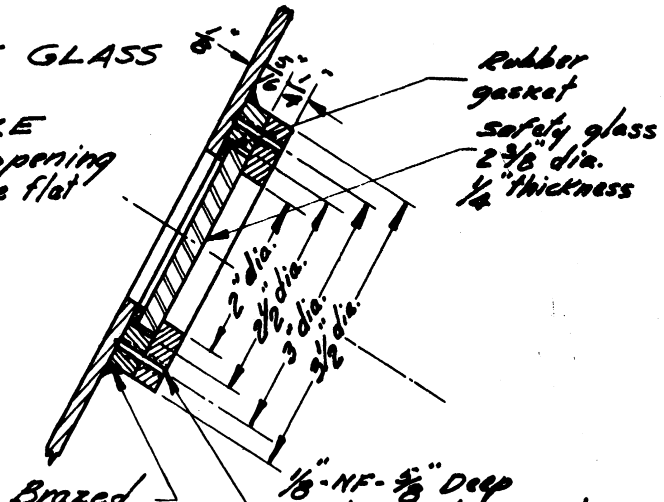
1-REQ'D.



DETAIL OF SIGHT GLASS FIXTURE

SCALE - 1/2 SIZE

The shell wall around the opening should be formed to fit the flat sight glass fixture



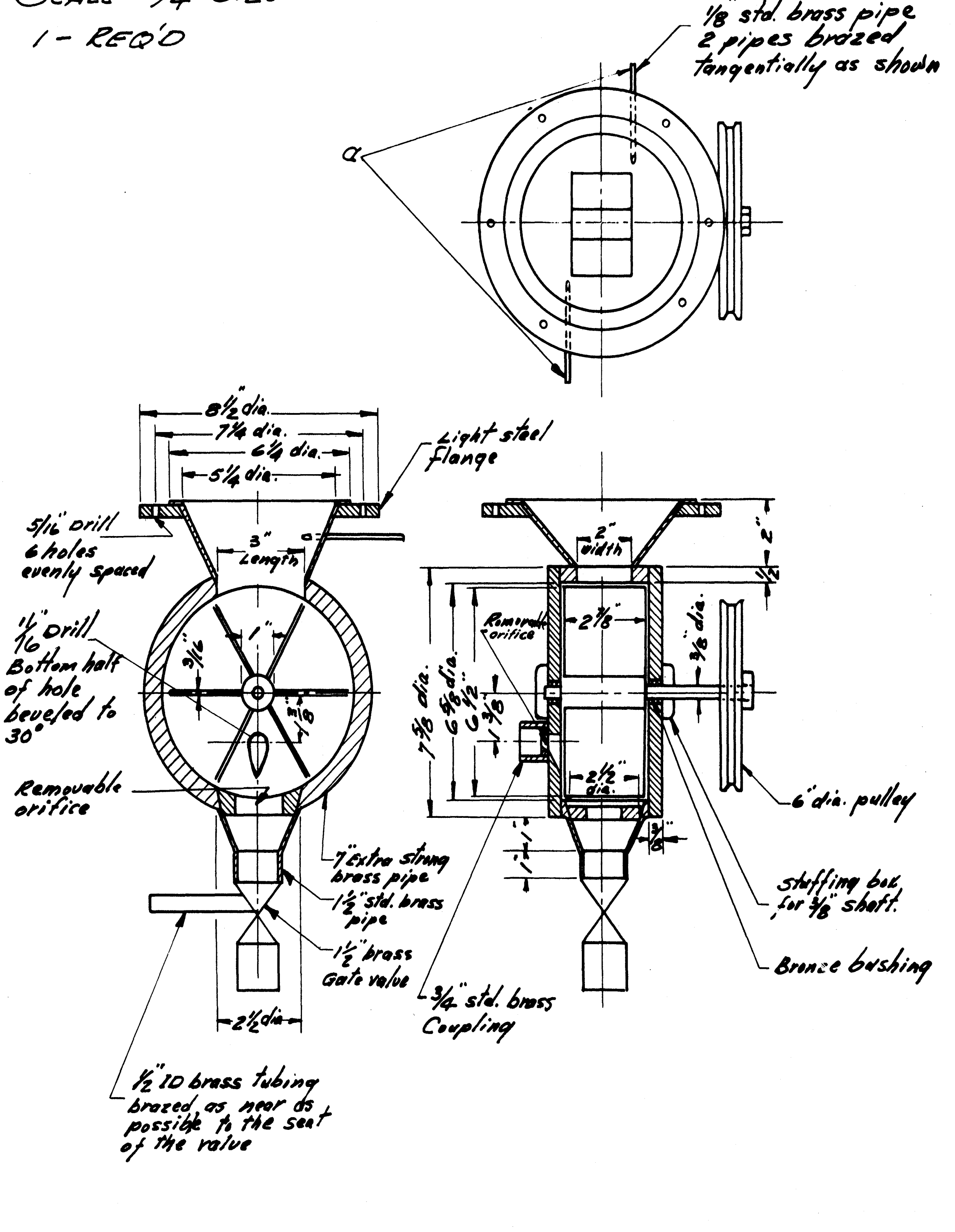
NO. 12

DRUM DISTRIBUTOR & 1/4 HP VARIABLE SPEED DRIVE, 50-150 RPM.

BRASS CONSTRUCTION EXCEPT SHAFT & PULLEY

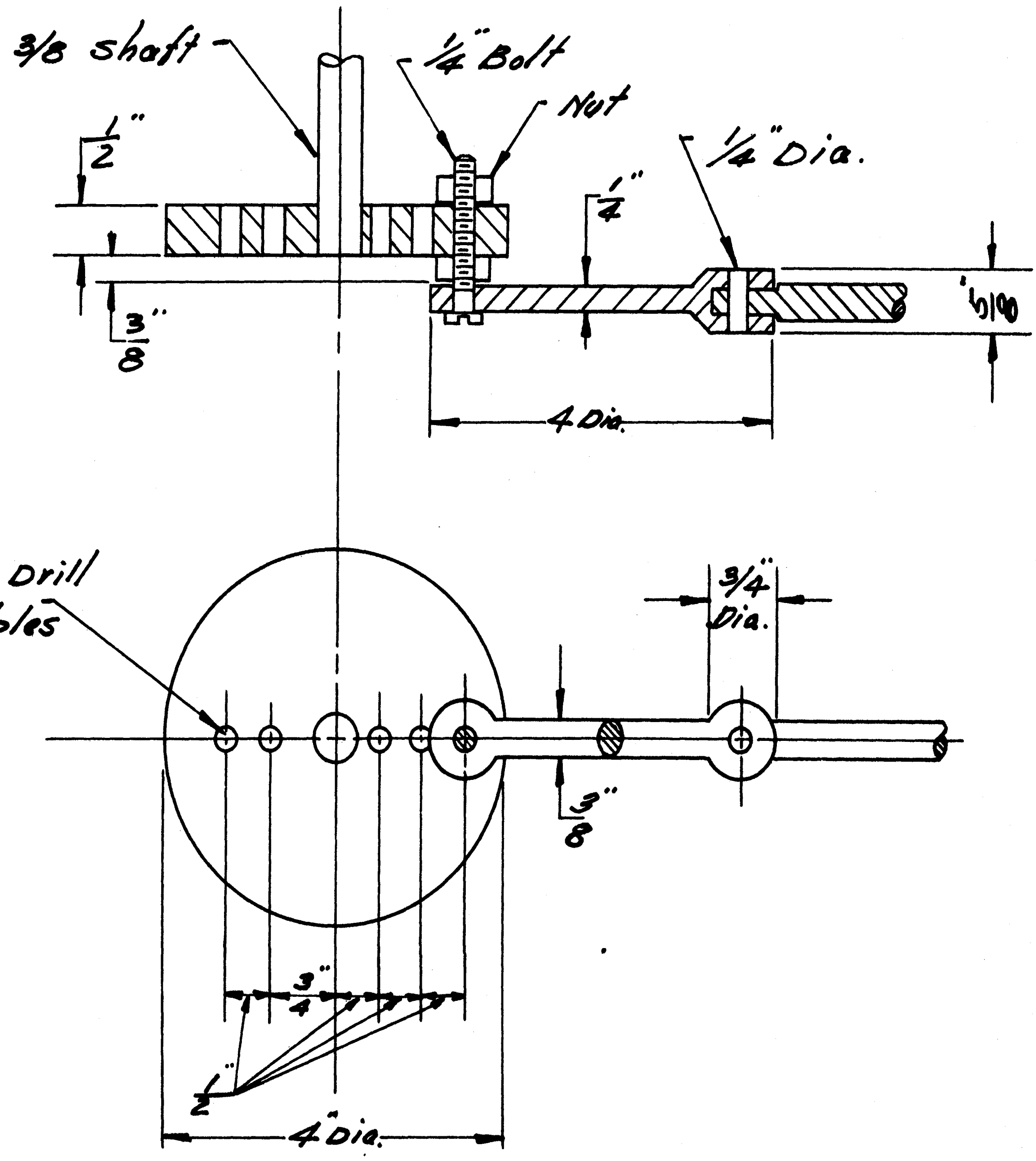
SCALE- 1/4 SIZE

1 - REQ'D



NO. 13

ECCENTRIC PULLY & CONNECTING ROD WITH 1/4 HP
VARIABLE SPEED DRIVE, RPM-50-100
STEEL CONSTRUCTION
SCALE-1/4 SIZE
1-REQ'D.



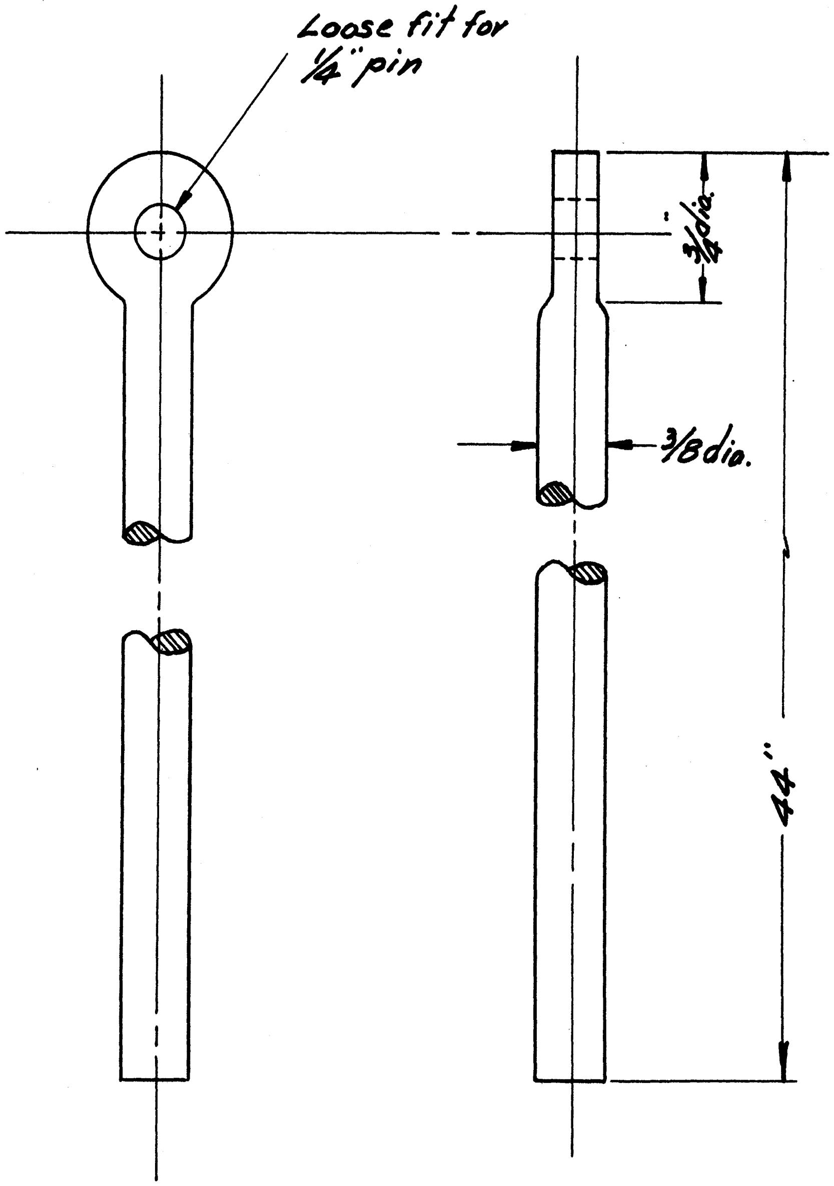
No. 14

SHAFT - DETAIL SKETCH

BRASS CONSTRUCTION

SCALE - FULL SIZE

1 - REQ'D



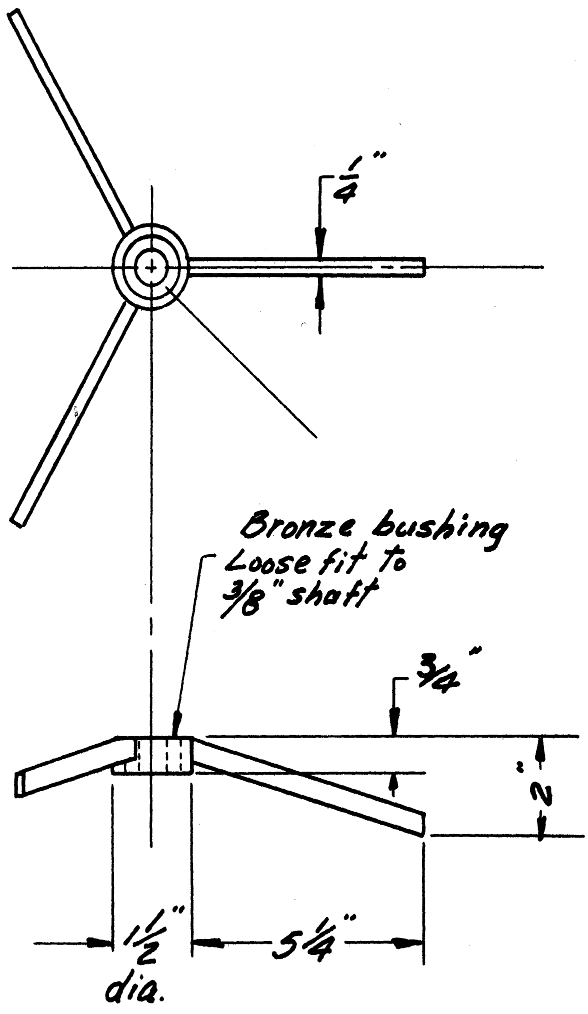
No. 15

SHAFT SUPPORT - DETAIL SKETCH

BRASS CONSTRUCTION

SCALE - 1/4 SIZE

2 - REQ'D



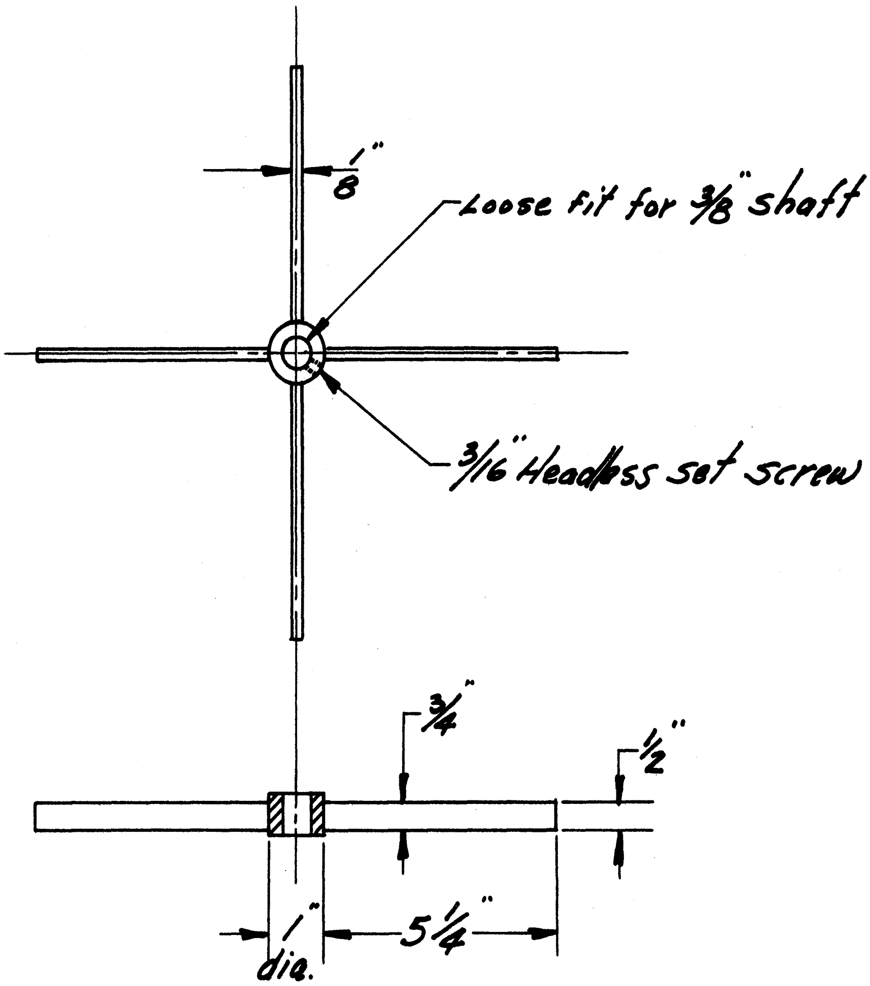
NO: 16

PADDLE - DETAIL SKETCH

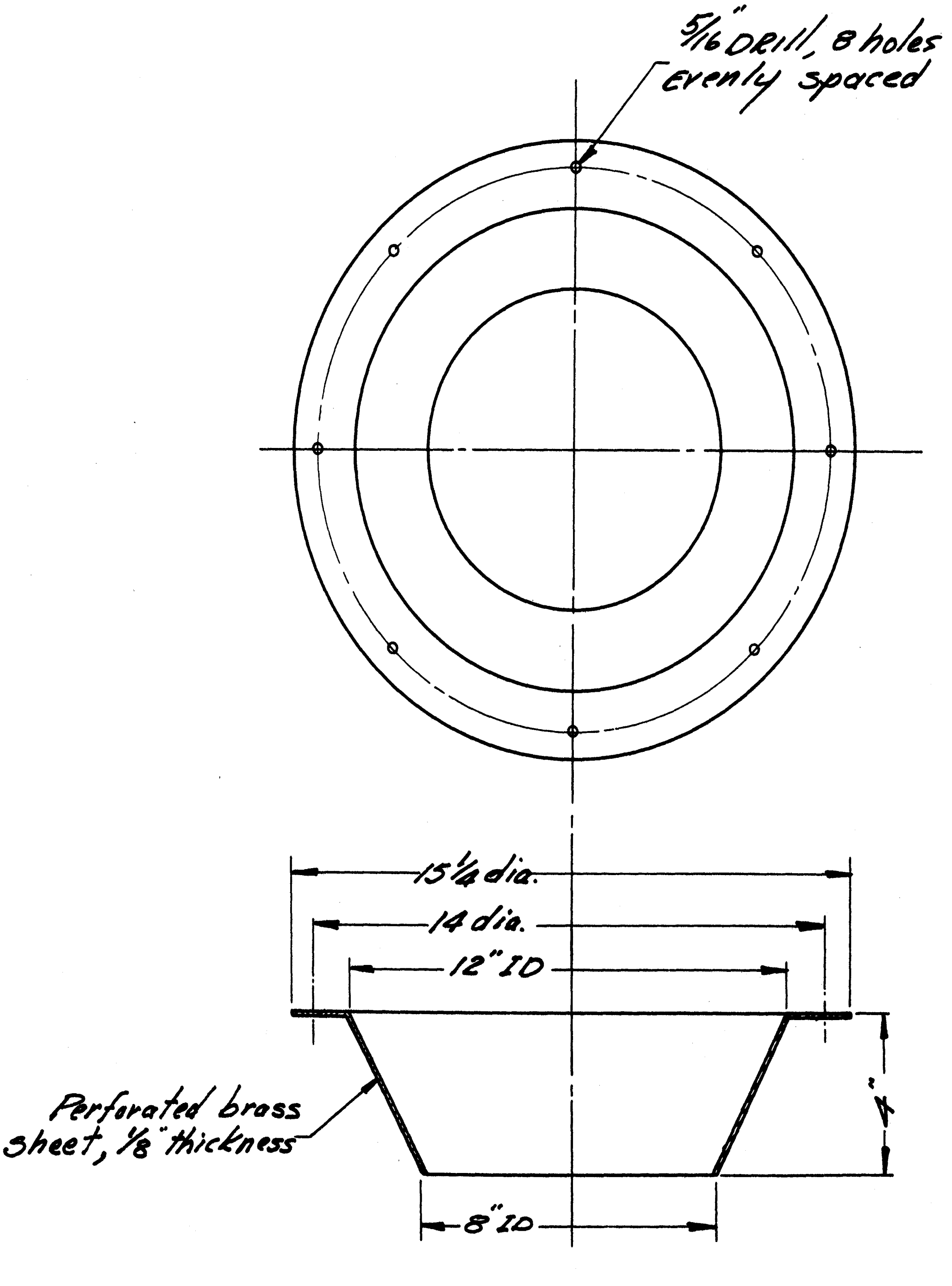
BRASS CONSTRUCTION

SCALE - 1/4 SIZE

6 - REQ'D



NO. 17
PERFORATED CONE - DETAIL SKETCH
BRASS CONSTRUCTION
SCALE - 1/4" SIZE
1 - REQ'D



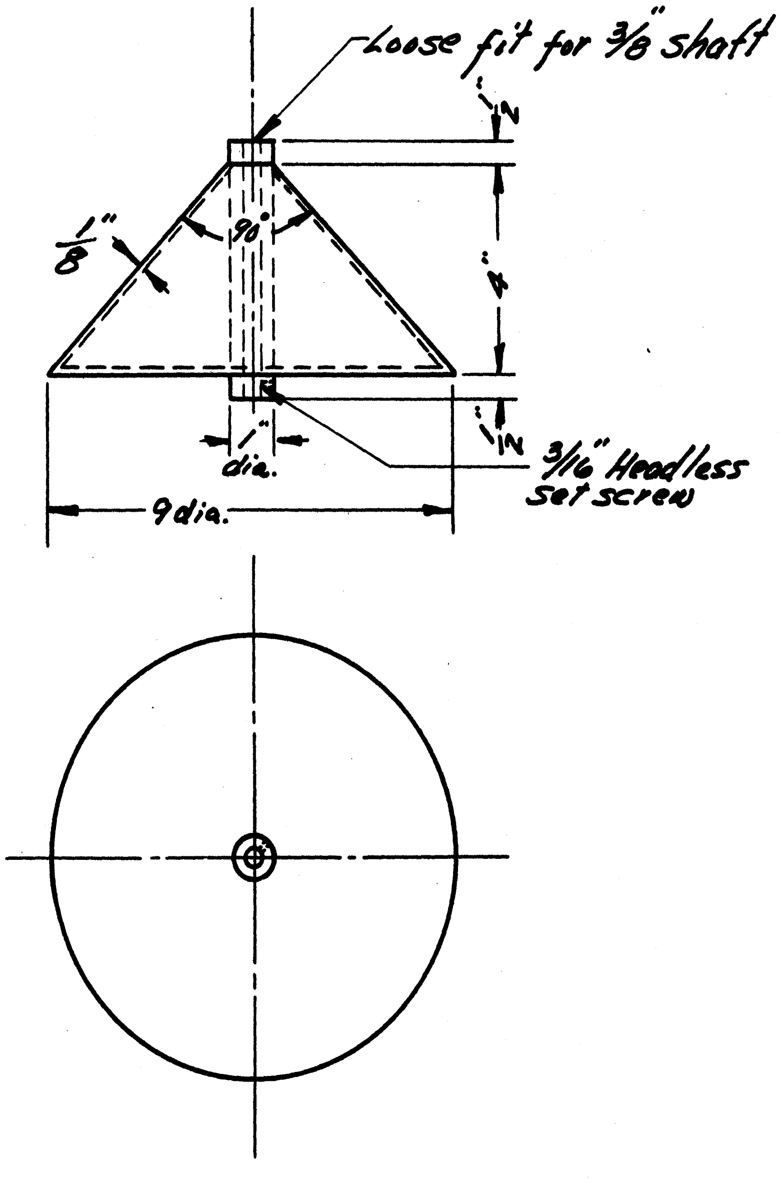
NO. 18

DISTRIBUTOR CONE- DETAIL SKETCH

BRASS CONSTRUCTION

SCALE-1/4 SIZE

1-REQ'D



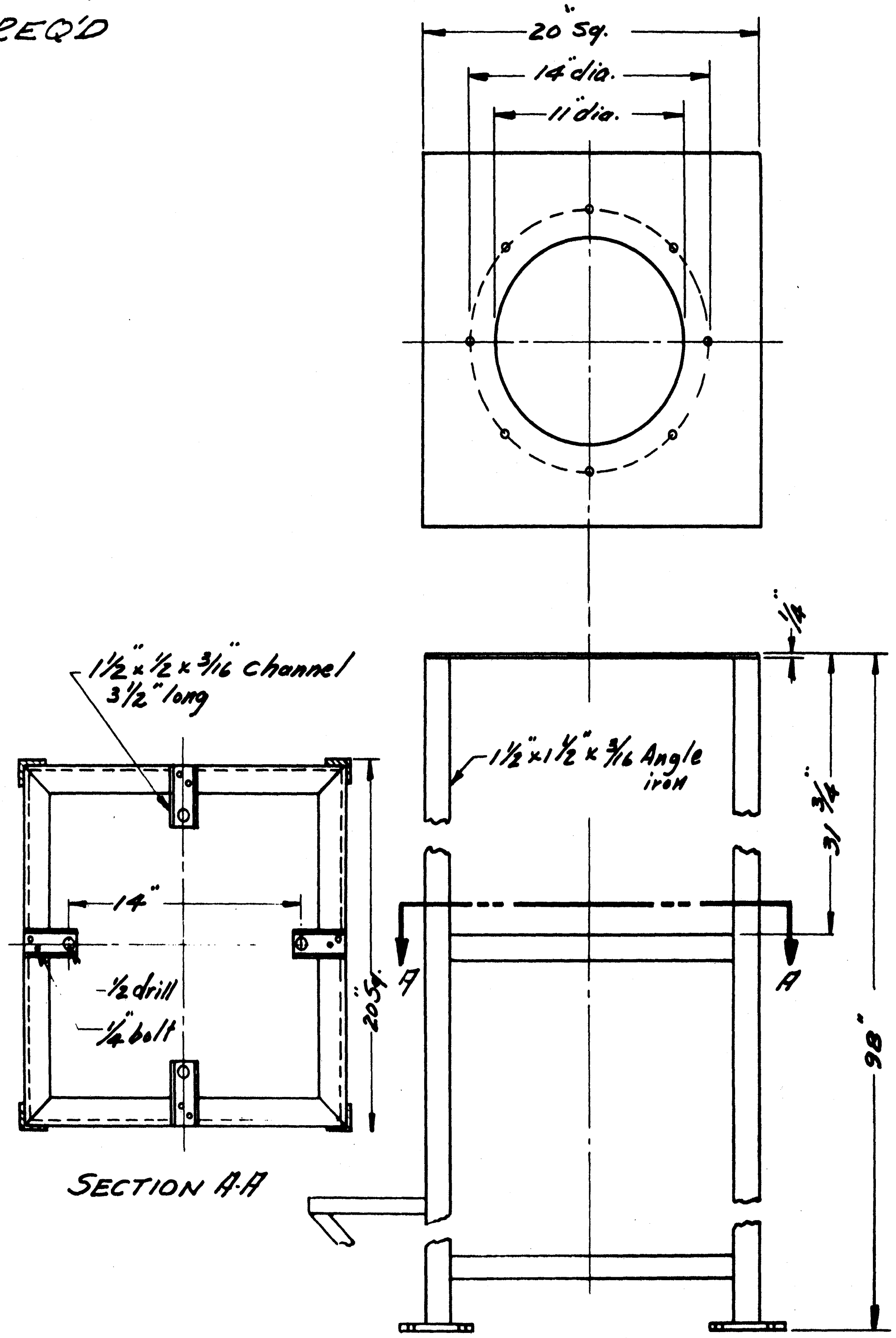
NO. 19

FEEDER SUPPORT - DETAIL SKETCH

IRON CONSTRUCTION

SCALE - 1/8 SIZE

1 - REQ'D



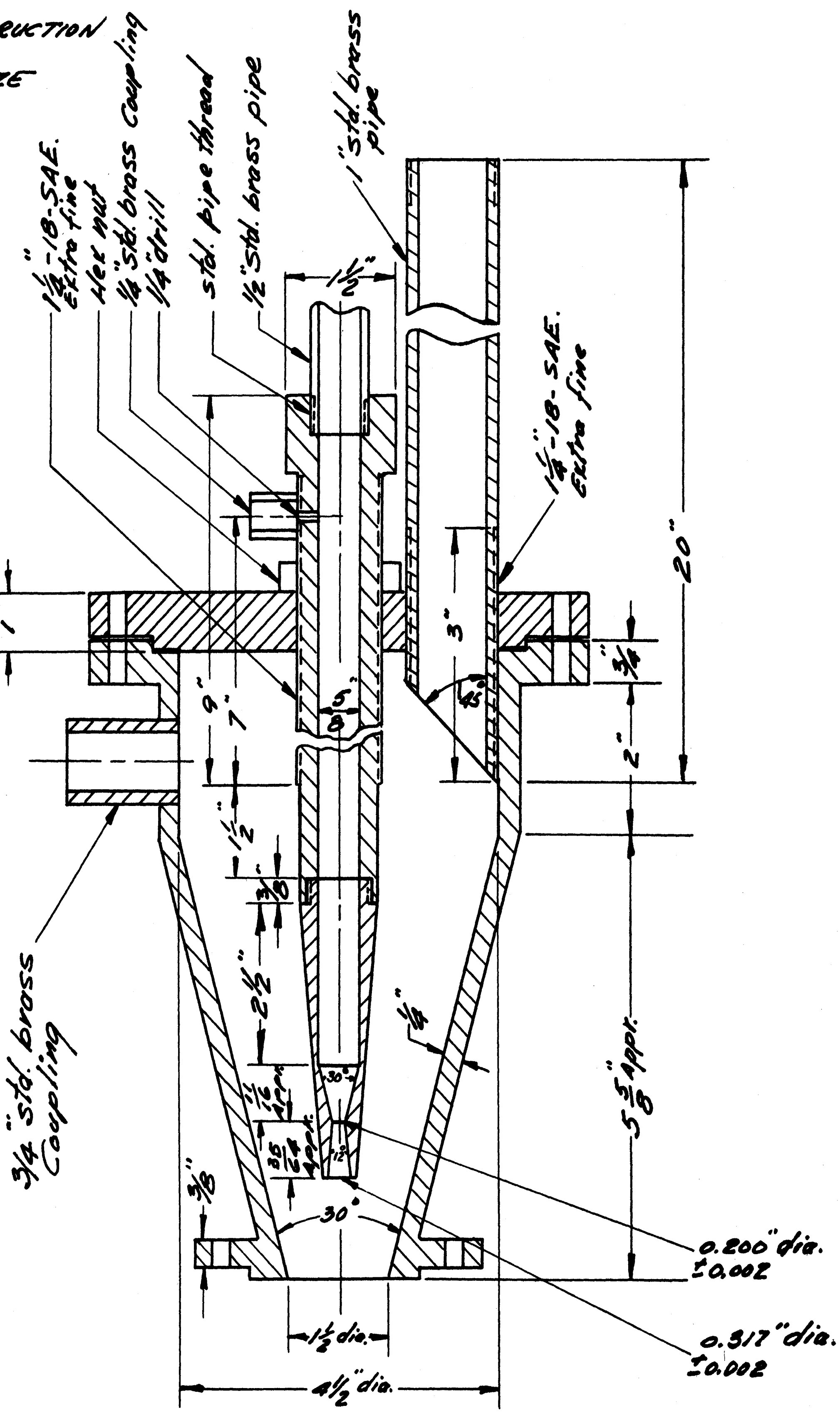
NO. 20

EJECTOR

BRONZE CONSTRUCTION

SCALE - 1/2 SIZE

1 - REQ'D



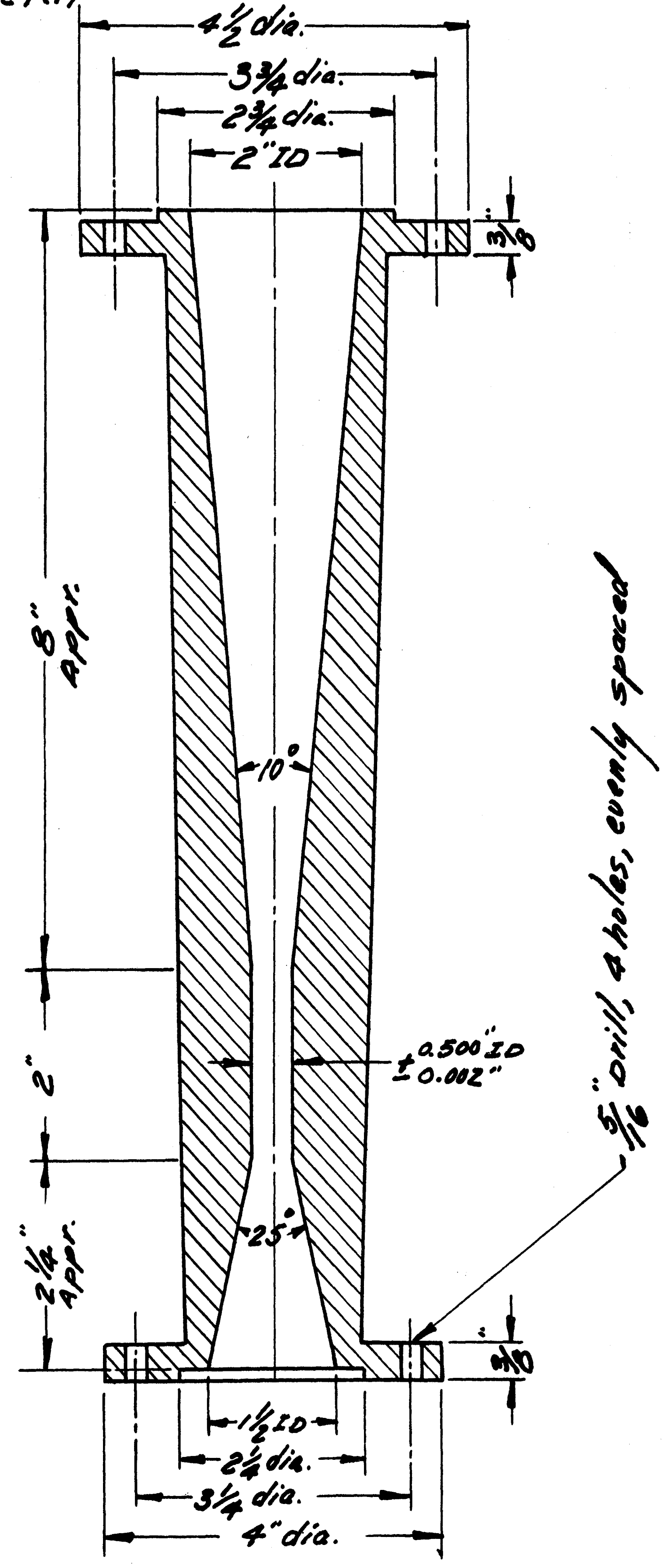
No. 21

DIFFUSER NO. 1 - DETAIL SKETCH

BRONZE CONSTRUCTION

SCALE - 1/2 SIZE

1 - REQ'D



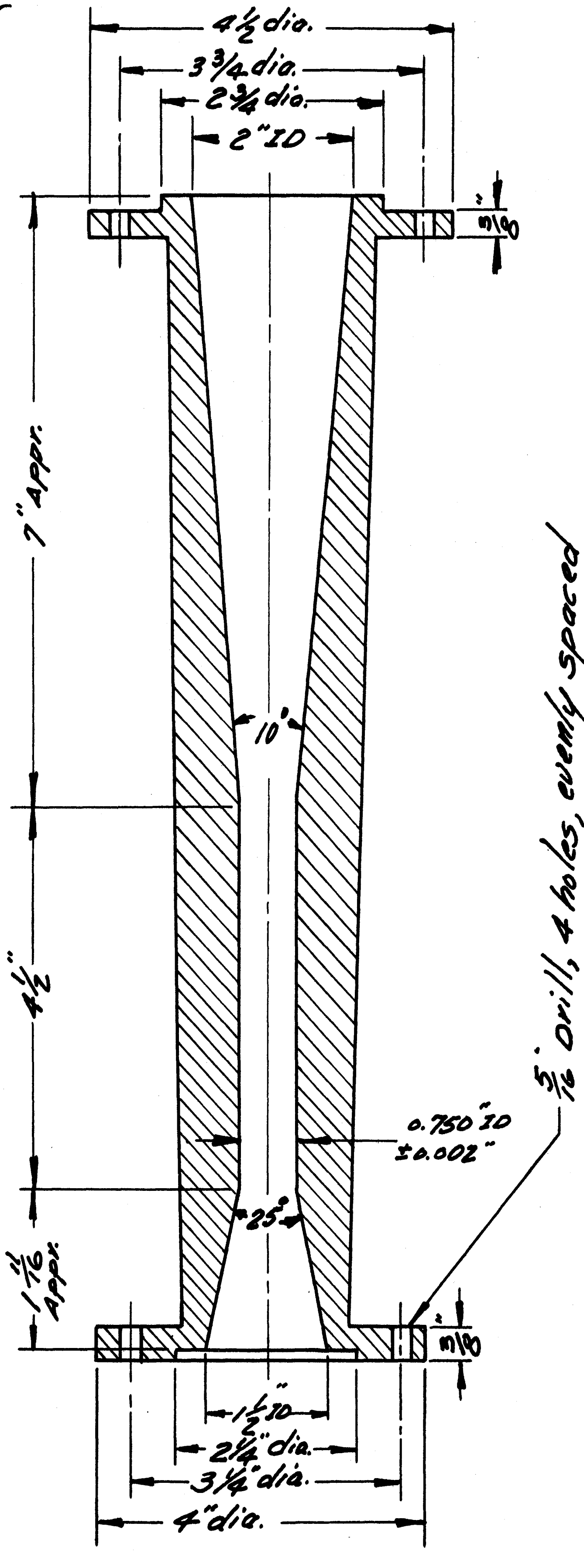
NO. 22

DIFFUSER NO. 2 DETAIL SKETCH

BRONZE CONSTRUCTION

SCALE-1/2 SIZE

1-REQ'D.



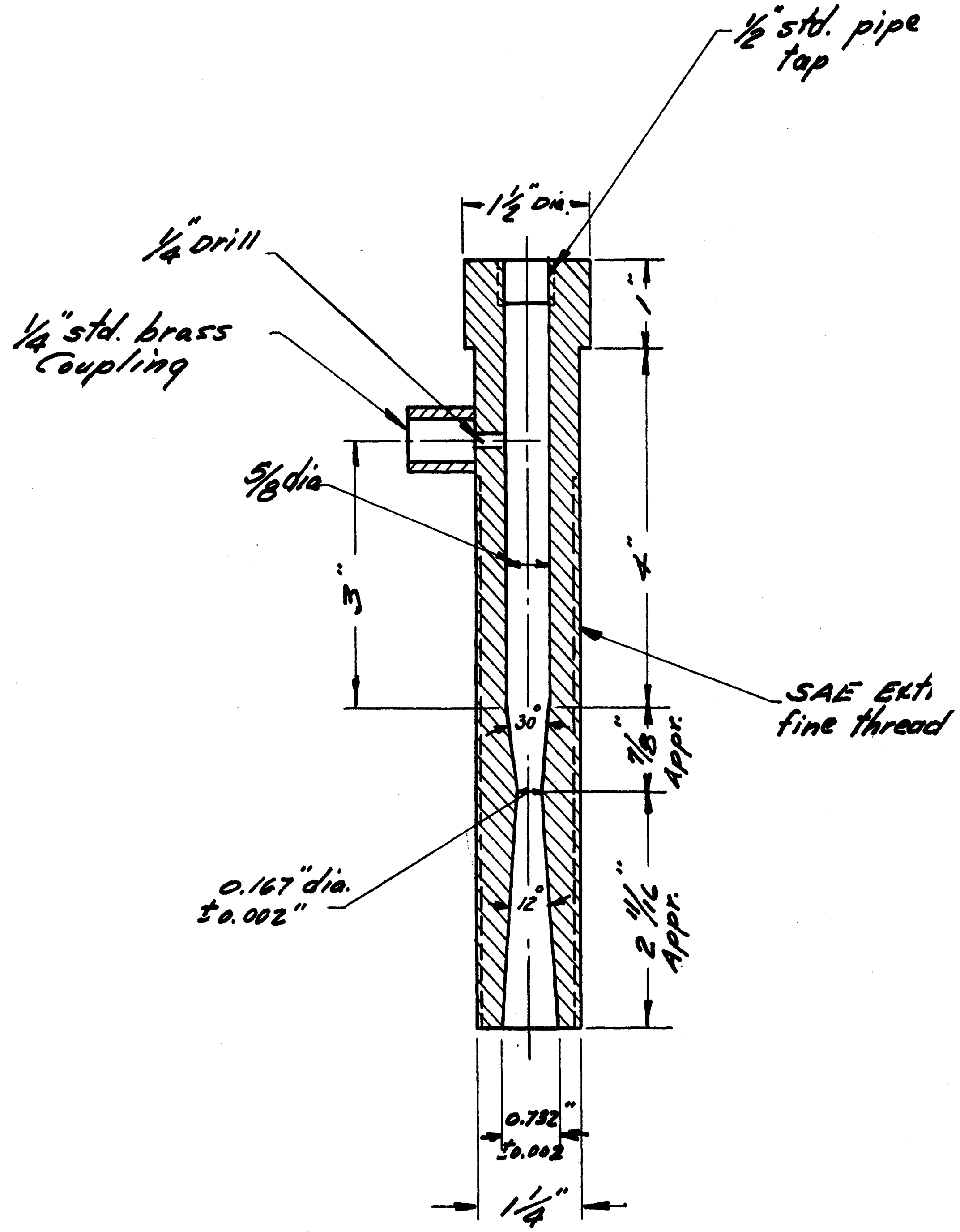
NO. 23

SPARE STEAM NOZZLE - DETAIL SKETCH

BRONZE CONSTRUCTION

SCALE - 1/2 SIZE

1 - REQ'D



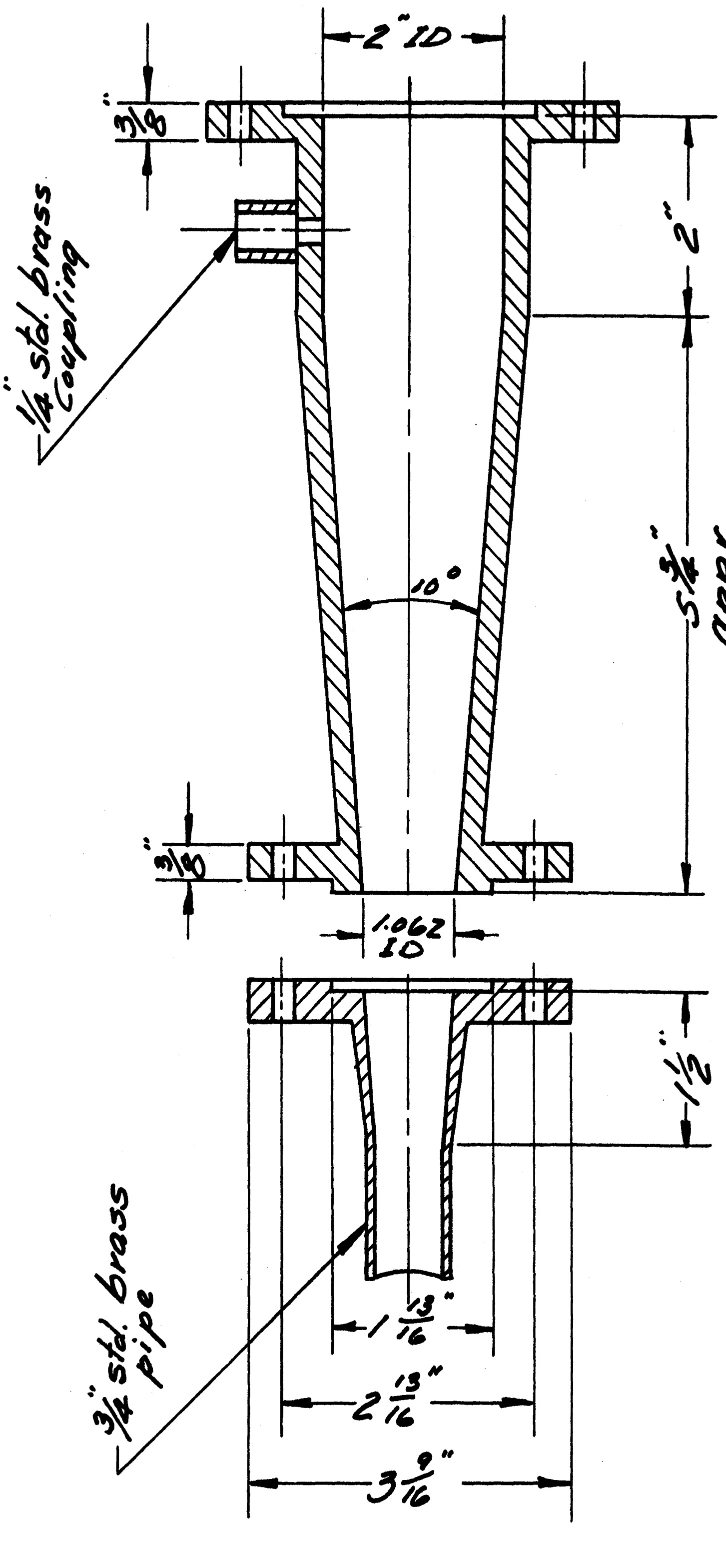
NO. 24

DIFFUSER TAIL PIPE - DETAIL SKETCH

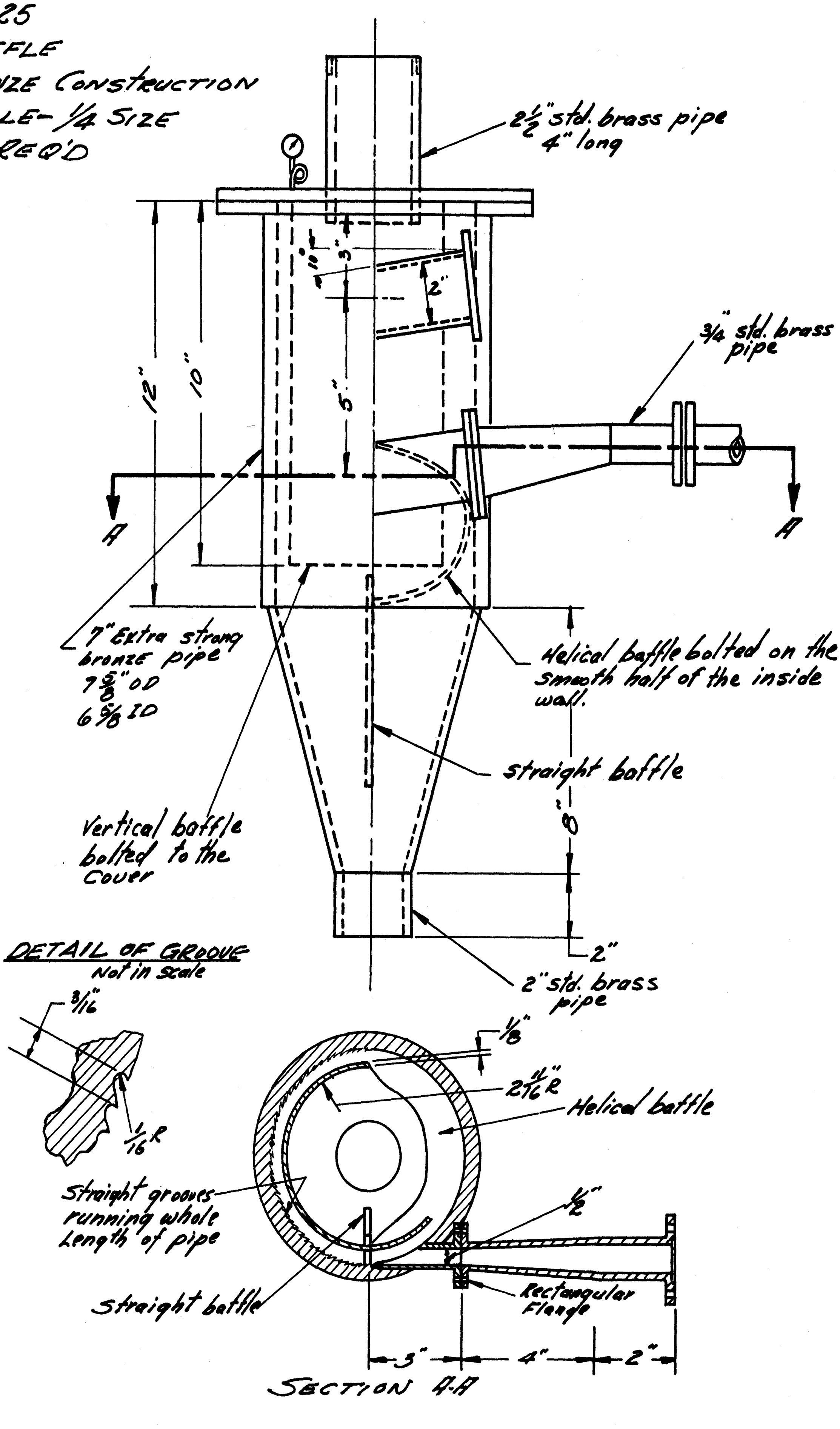
BRONZE CONSTRUCTION

SCALE - 1/2 SIZE

1 - REQ'D



No. 25
BAFFLE
BRONZE CONSTRUCTION
SCALE– 1/4 SIZE
1– REQ'D



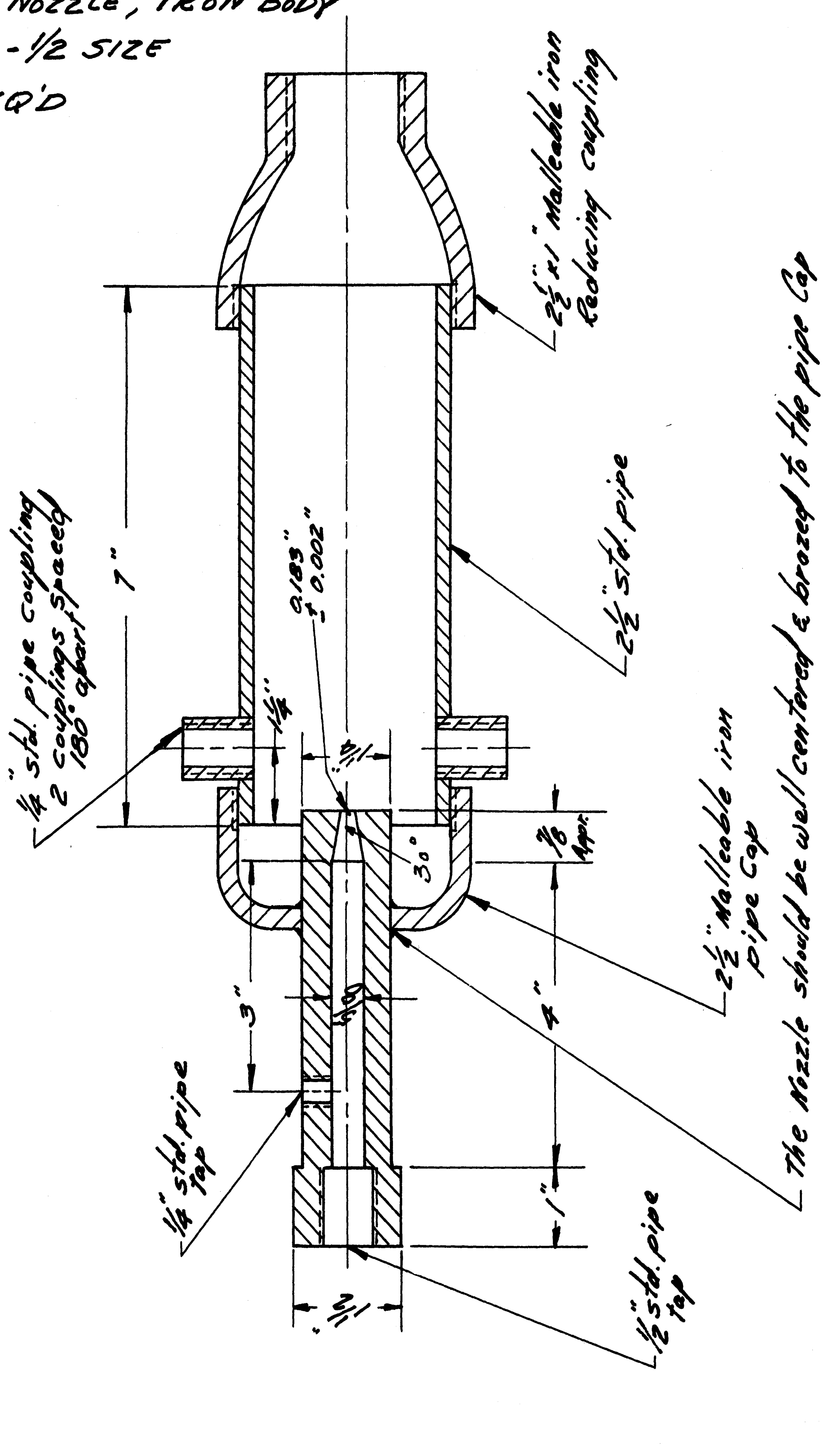
NO. 26

METERING NOZZLE

BRASS NOZZLE, IRON BODY

SCALE - 1/2 SIZE

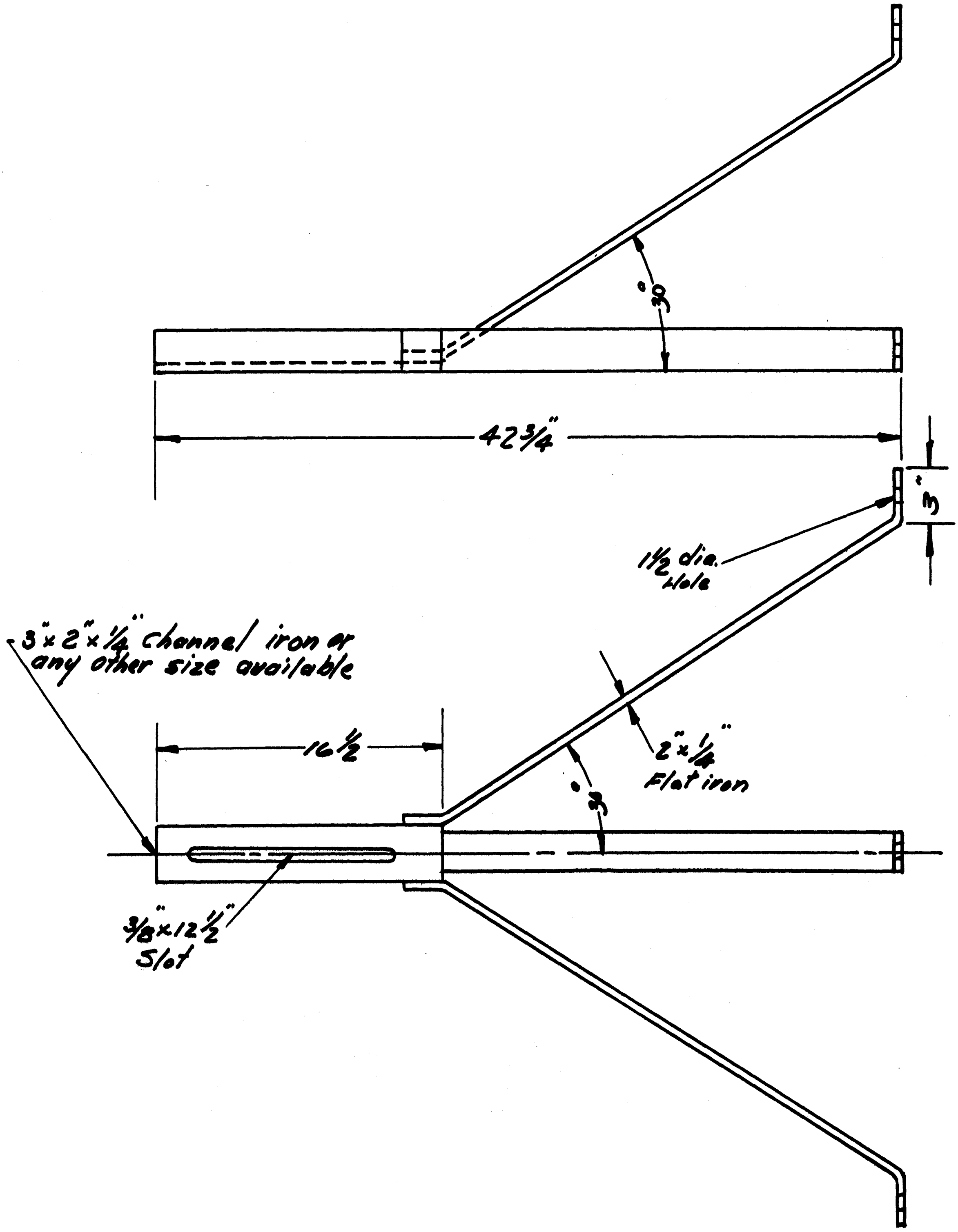
1 - REQ'D



No. 27

EJECTOR & PIPE SUPPORT

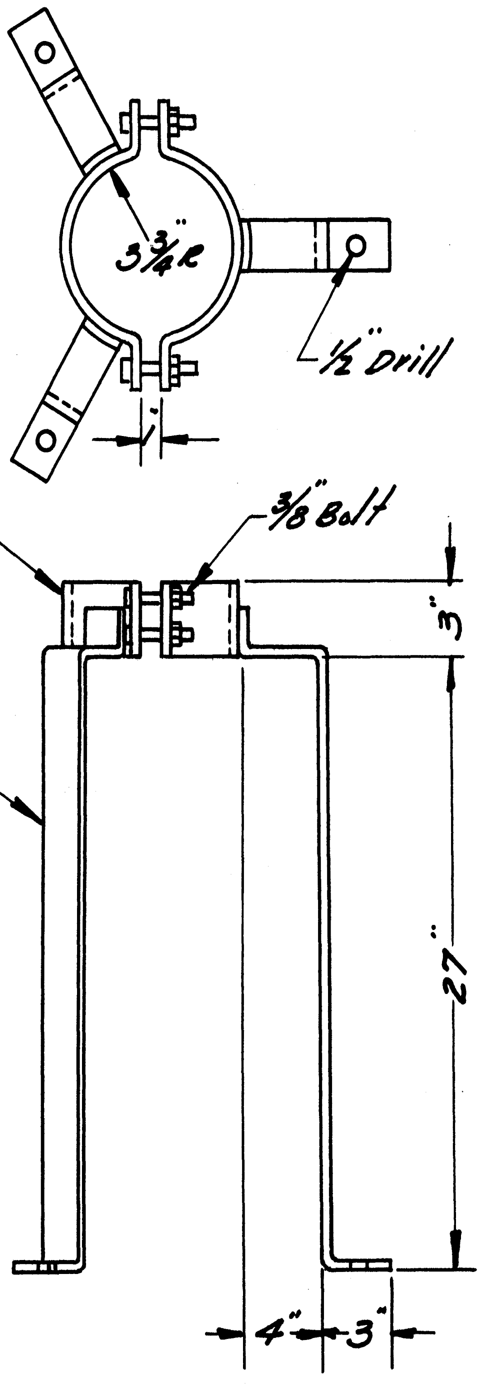
4- REQ'D



NO. 28

BAFFLE SUPPORT

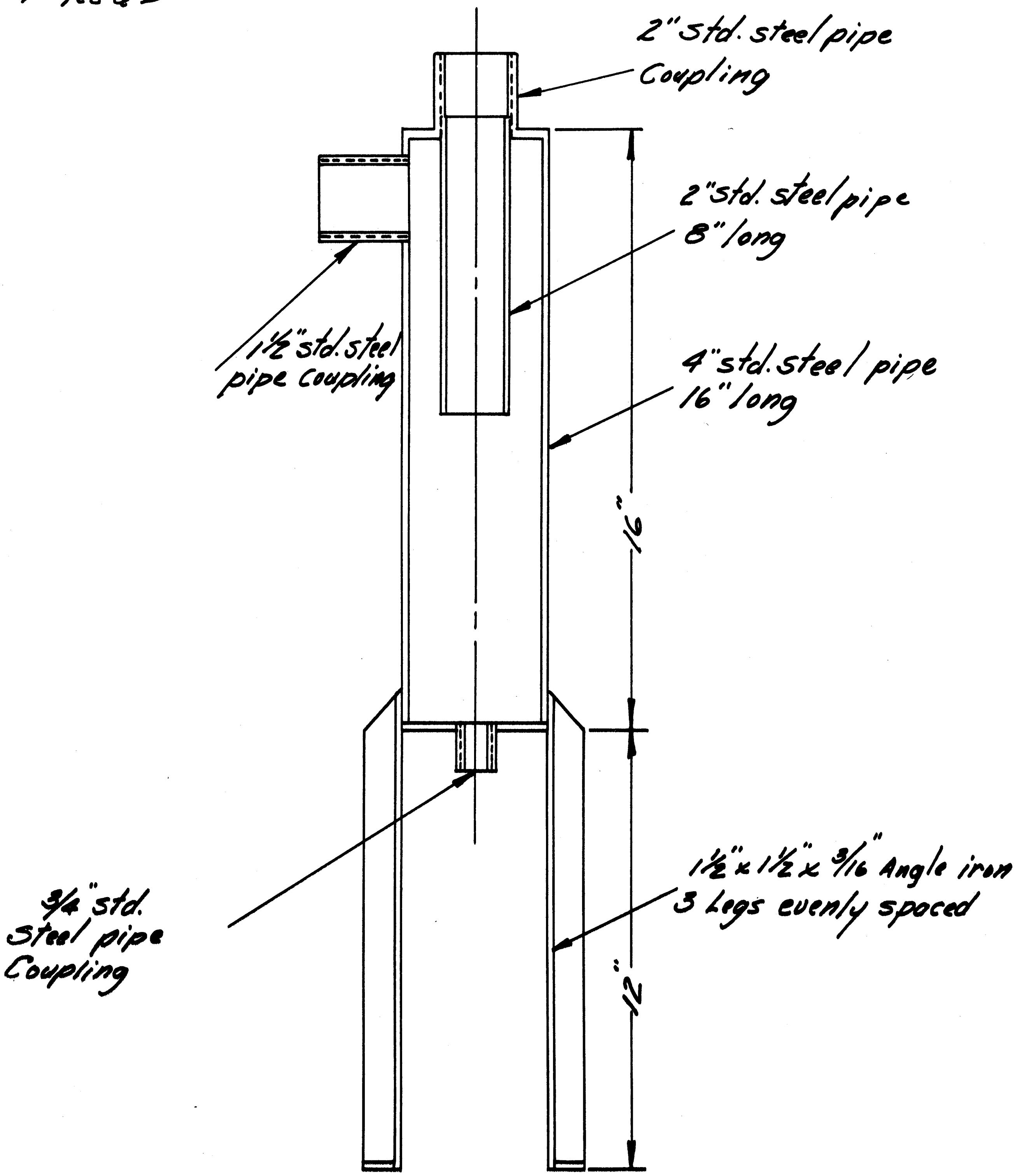
1- REQ'D



NO. 29

CONDENSATE SEPARATOR

1-REQ'D

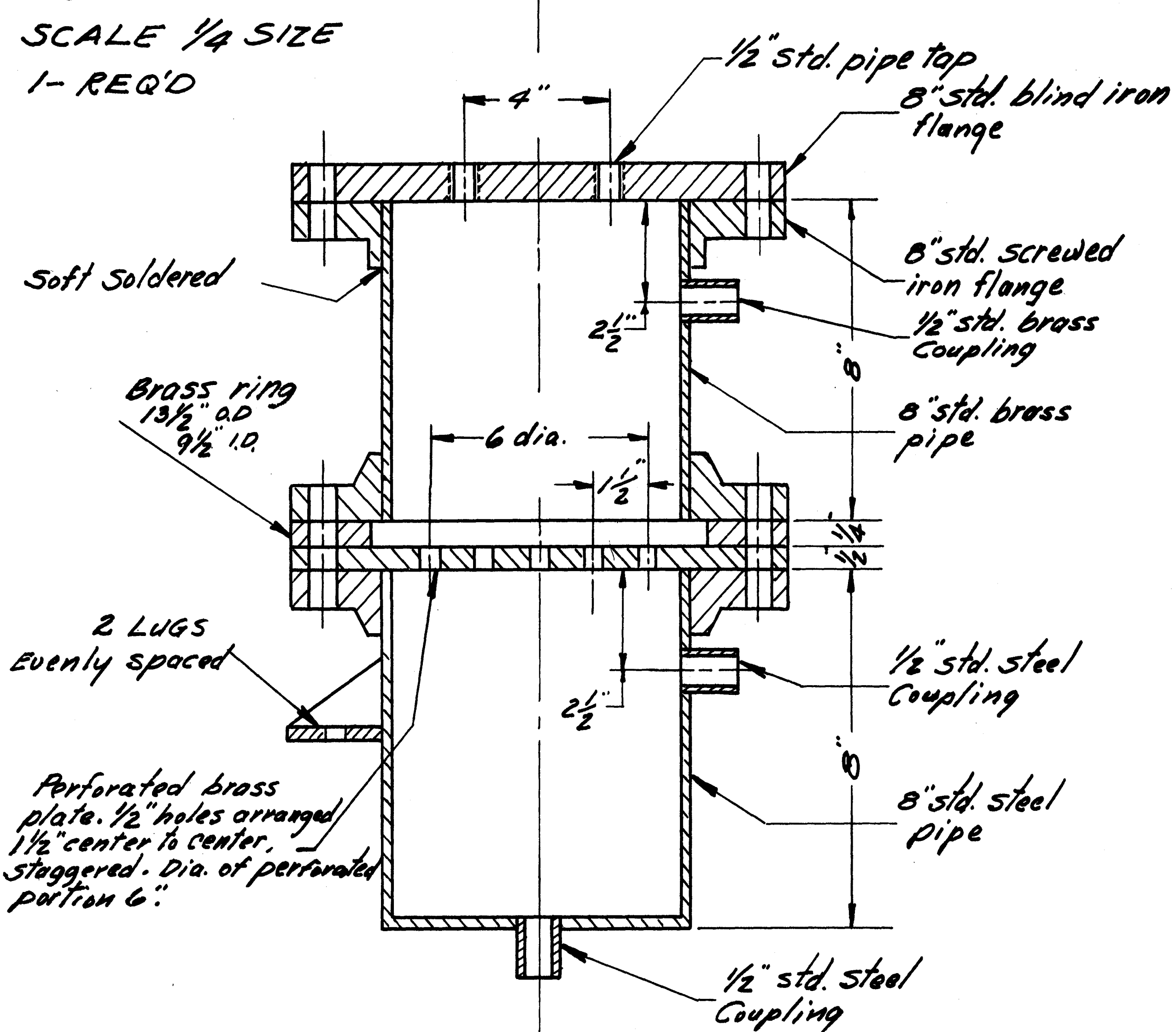


No. 30

JUICE SEPARATOR & LINING

SCALE 1/4 SIZE

1- REQ'D



JUICE SEPARATOR LINING