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The design and construction of a pneumatic harvester for crimson clover seed

Herbert Dean Sullivan

To the Graduate Council:

I am submitting herewith a thesis written by Herbert Dean Sullivan entitled "The design and construction of a pneumatic harvester for crimson clover seed." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

M. A. Sharp, Major Professor

We have read this thesis and recommend its acceptance:

R. L. Maxwell, C. A. Newton, John. B. Liljedal

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

August 1, 1951

To the Graduate Council:

I am submitting herewith a thesis written by Herbert Dean Sullivan entitled "The Design and Construction of a Pneumatic Harvester for Crimson Clover Seed." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

M A Sharp

Major Professor

We have read this thesis and recommend its acceptance:

R. L. Maxwell

[signature]

John B. Liljedahl

Accepted for the Council:

C. A. Waters

Dean of the Graduate School

THE DESIGN AND CONSTRUCTION
OF A PNEUMATIC HARVESTER
FOR CRIMSON CLOVER SEED

A THESIS

Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

by

Herbert Dean Sullivan

August 1951

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ACKNOWLEDGMENTS

In making this study I have received much help and criticism which I should like to acknowledge. For directing my approach to the study, as well as for much sound advice and able criticism, I am greatly indebted to Professor M. A. Sharp, my major professor. To Professors R. L. Maxwell, C. A. Newton, J. B. Liljedahl, and Mr. H. A. Arnold for their encouragement and many helpful suggestions, I am also deeply grateful. For willingly helping in the construction of the experimental attachment, I want to thank Mr. James Butler and Mr. W. E. Huston. I wish, too, to express my gratitude to Mrs. Orlo Myers for her cooperation and patience in typing this thesis.

CHAPTER I

THE PROBLEM

The Importance of Crimson Clover

Crimson clover (Trifolium incarnatium) is one of the most important winter annual legumes of the central section of the Eastern states. Besides being an excellent pasture plant and furnishing an abundance of hay, it gives protection to the soil during the fall, winter, and spring, prevents soil erosion, and provides green manure for soil improvement.

Crimson clover became important in this country in 1880, and the acreage has been steadily increasing since that date. During the period from 1940 to 1945 the annual commercial consumption of seed ranged from 6 to 18 million pounds as compared with 2 million pounds consumed in 1935.[1] A recent crop reporting release says of the popularity of crimson clover:

> The popularity of crimson-clover for winter grazing, cover crop, and soil improvement has been on the increase for a number of years and a large acreage was planted last fall. . . . In spite of low yields, which caused some abandonment of acreage intended for harvest, and inability to harvest because of rains the acreage that will be harvested for seed this year is indicated at 103,600 acres.

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[1] E. A. Hollowell, Crimson Clover, Leaflet No. 160 (rev. ed.; Washington, 1947), p. 2.

> This will represent the largest acreage of crimson clover seed ever harvested, being 17 percent larger than the five-year average of 63,740 acres.[2]

The soil improvement resulting from the growing of crimson clover makes it highly desirable that the acreage seeded to this crop be increased as much as possible in all sections where it is adapted.

<u>Characteristics of the Crop Which Affect the Seed Harvest</u>

Crimson clover planted in the fall develops flower stems in the spring. These stems grow rapidly and terminate their growth with long pointed flower heads. The seeds form and mature progressively from the bottom of the flower head upward. During seed formation the ovary wall enlarges and forms a tight papery pod around each seed. The seeds, each wrapped in its ovary wall, shatter easily as soon as they reach maturity.

The tendency on the part of the plants to shatter their seed as soon as they mature and the difficulty encountered in threshing the seed out of the ovary walls, or seed pods, are the two characteristics of the crop which most affect the seed harvest. Mr. Hendricks says:

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[2] Federal-State Cooperative Crop Reporting Service, "Crimson-Clover Seed Crop," Release No. 1050 (Nashville, June 26, 1950).

"As soon as crimson clover seeds are ripe they shatter. They also shatter easily when handled dry before the seeds are ripe. Harvesting crimson clover seed would be difficult even if one could depend upon good weather."[3] A beating rain may shatter much of the seed if the crop is allowed to stand after ripening;[4] therefore, when a considerable acreage is to be harvested and the crop is uniformly mature, it is well to start harvesting early to avoid as much field shattering as possible.[5] Extreme care, however, must be exercised in handling the green or damp grain to avoid heating, which lowers the germination and consequently the market value of the grain.[6] At best, the usual solution to the shattering problem is some compromise between harvesting the seed crop too early and taking the risk of losing the seed in storage, and waiting until the crop is mature and taking the risk of a heavy loss in shattered seed. The loss due to the seed's not being threshed from the seed pod is usually low and can be reduced to a negligible value if

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[3] H. E. Hendricks, Questions and Answers Concerning the Use of Crimson Clover in Tennessee in 1941, Agricultural Extension Service, Special Circular No. 146 (University of Tennessee, Knoxville, Tennessee, April 10, 1941), p. 5.

[4] Hollowell, *op. cit.*, p. 8.

[5] W. M. Hurst and W. R. Humphries, Harvesting with Combines, Farmers' Bulletin No. 1761 (rev. ed.; Washington, 1947), pp. 35-36.

[6] *Ibid.*, p. 17.

the harvester operator has sufficient knowledge and skill in adjusting the machinery.

The extent to which seed producers must rely on favorable weather conditions during the harvesting period is so great that inclement weather in one producing area may seriously affect the national yield. The crop reporting service release of 1949 states:

> Weather conditions during the winter and spring months were very favorable in virtually all important producing sections for the growth of crimson clover, and yields of seed showed promise of being the best in many years. However, heavy rains, high winds, and some hail damage in local areas caused considerable lodging and shattering of seed in Georgia, Tennessee, and Alabama toward the end of the harvesting season. These damage factors, together with the facts that much of the crimson clover acreage in new areas of seed production was pastured until early April and a larger than usual percentage of the crop was grown with companion crops such as barley, resulted in relatively low yields this year. The United States yield of 207 pounds per acre is 11 percent smaller than last year and 9 percent below average.[7]

The element of chance due to the weather is, therefore, large enough to warrant an intensive study of probable solutions to the problem of harvesting crimson clover in the most efficient and economical manner.

<u>Present Methods of Harvesting and Their Shortcomings</u>

The present methods of harvesting crimson clover seed

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[7] Federal-State Cooperative Crop Reporting Service, "Crimson-Clover Seed Crop," Release No. 940 (Nashville, June 28, 1949).

are as follows: (1) Seed is combined direct from the stand or from the windrow; (2) clover is cut and cured in small bunches and threshed or hulled from the field; (3) clover is cut and cured in small bunches and either stacked or placed in the mow for threshing or hulling later; (4) seeds are stripped from the heads either by hand or with a horse-drawn stripper; (5) heads are caught in a pan or in a cloth receptacle behind a mowing machine cutter bar; (6) if sown with a companion crop, seed is combined or cut with a binder and shocked for later threshing;[8] (7) seed is vacuum harvested, collected along with other plant material in a screened frame on a trailer, and either threshed or cleaned, depending upon the hulling effect of the fan used.[9]

The harvesting methods mentioned above fall short of an efficient, economical method of harvesting the seed crop. The combine method, (1) above, is economical and efficient for most crops, but all grains except rice must be ripe and dry for the successful operation of the combine.[10] Crimson clover in this ripe, dry stage is very easily shattered and, consequently, is at the mercy of the weather, which may cause shattering of far more than half of the seed in a matter of hours. This method, however, results

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[8] Hendricks, op. cit., pp. 4-5.

[9] Personal letter from Isham J. Dorsey, June 27, 1951.

[10] Hurst and Humphries, op. cit., p. 17.

in a relatively low shattering loss if the weather conditions are ideal and the harvesting is well timed. Harvesting from the windrow is dependent also upon good weather. A hard cross-wind may pile up the windrows along the fence or twist them into tangled masses and thus cause a great loss of seed. "Rain often causes more shattering to the cut crop than to a standing crop."[11] Methods (2) and (6) above are also subject to the weather hazards mentioned previously for windrowed crops as well as to some shattering loss because of handling. Method (3) above usually results in heavy shattering losses because of the large amount of handling involved. Methods (4), stripping, and (5), clipping the heads, result not only in shattering losses during the cutting or stripping operation but also in a yield that is very bulky for handling. Crimson clover in the unhulled stage contains about two pounds of clean seed per bushel. "Its bulky nature makes unhulled seed more difficult to distribute uniformly than hulled seed. . . . It is also difficult to market and is not generally handled by the seed trade."[12] The vacuum method of harvesting mentioned above, method (7), also involves the handling of very bulky

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[11] Lawrence Jenkins, _Harvesting Seed of Vetches, Winter Peas, Crimson Clover, Ryegrass_, Oregon Agricultural Extension Service, Bulletin No. 597 (Corvallis, Oregon, 1942), p. 8.

[12] Hollowell, _op. cit._, p. 6.

material. Mr. J. L. Butt says of this method: "We have seen some unclean seed from Mr. Dorsey's harvester and can testify that large quantities of trash are picked up in addition to the seed."[13] The resultant losses of the various harvesting methods vary from year to year, but the average loss in shattered seed is estimated at about 50 percent.[14]

Problem Presented

The current problem in harvesting crimson clover seed is not new. As early as 1915, Mr. J. M. Westgate recognized the shattering tendency of the plant as the principal drawback in harvesting the seed crop.[15] The problem is to reduce or to eliminate the possibility of an appreciable loss of seed caused by shattering both before and during the harvesting process.

Proposed Solution

The problem can be approached in two ways. First, a shatter-resistant strain of crimson clover, which would be well adapted to direct combine harvesting, might be developed through plant breeding; this method of approach, however,

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[13] Personal letter from J. L. Butt, Associate Agricultural Engineer, Alabama Polytechnic Institute, Auburn, Alabama, Nov. 21, 1950.

[14] Hendricks, *op. cit.*, p. 2.

[15] J. M. Westgate, *Crimson Clover: Seed Production*, Farmers' Bulletin No. 646 (Washington, D. C., 1915), p. 8.

would probably require several years of breeding and might even then not be successful. Secondly, as this study proposes to show, a satisfactory solution to the problem can be reached by making a change in the harvesting machinery.

The purpose of this study is to arrive at a design for an attachment to be used on a combine. The function of this attachment will be to recover shattered crimson clover seed during the direct combining process and to deliver the recovered seed to the threshing cylinder of the combine. In an effort to evaluate the design, an experimental attachment has been constructed and tested both in the laboratory and in the field.

CHAPTER II

SURVEY OF EXISTING PNEUMATIC HARVESTING MACHINES

A survey of the literature concerning pneumatic harvesting machines has revealed a number of designs which have been applied more or less successfully to several different crops, among them various seed crops, nuts, alfalfa and other hay crops.[1] However, an efficient and practicable pneumatic harvesting machine for crimson clover seed has not been developed. The machines which in the opinion of the author are most closely related to the study of this problem will be discussed individually, according to the crop harvested.

Ladino Clover

A vacuum harvesting machine was first used successfully to harvest Ladino clover seed about 1938, when "Wyatt and Dunne, a father and son-in-law team near Oakdale, Calif., rigged up their Farmall tractor with a pair of vacuum sweeps to harvest their crop."[2] A cyclone type of separator attached to the tractor was used to separate the seed from the air stream. The operation was so successful that Wyatt

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[1] F. Hal Higgins, "Air Power--the New Farm Hand," Compressed Air Magazine, LIII (Jan.-Dec. 1948), 263.

[2] Ibid., p. 265.

and Dunne got "a patent or two on the thing to keep the idea bottled up" and subsequently became the leading Ladino seed growers in California.[3]

Another grower who helped pioneer the vacuum harvesting of Ladino seed was George Fiack of Glenn County, California. Taking an idea from his wife's vacuum sweeper, Fiack attached a commercial blower to a 6-foot sweep, which he mounted to the back of his TD-9 crawler tractor. After harvesting his seed in the conventional manner, he ran the vacuum sweep over the stubble. During that season Fiack recovered $30,000 worth of seed from stubble in his neighbors' fields, proving that as much as $150 per acre was being lost by the use of traditional methods of harvesting.

Several other harvesters similar to Fiack's have been built and put into use in California. All of these are essentially pick-up devices which collect the seed, together with dirt, trash, et cetera, from the field. All of the material picked up is discharged into trailers and then taken to cleaning stations.[4]

Experimental work in methods of harvesing Ladino clover seed begun at Michigan State College in 1944 resulted in the development of a vacuum-type harvester.

The vacuum harvester consists of an exhauster-type blower mounted on a tractor and belt driven by

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3 Ibid.

4 Ibid.

> the tractor engine, a rotating beater contained within a suction nozzle and attached to the suction side of the blower with a 12-inch tube. Another 12-inch tube connects the discharge side of the blower to a trailing wagon with tight sidewalls. The top of the wagon is covered with burlap to prevent seed from blowing out. The suction nozzle of the harvester is 6 feet wide to t ake a normal swath. The blower is rated to move approximately 5,000 cubic feet of air per minute with sufficient vacuum to riase water 10 inches and uses 15 horsepower.[5]

Further experiments carried on in 1948 to obtain comparative field date indicate that vacuum-type harvesting recovers more Ladino seed than the more conventional methods of harvesting.[6]

Bur Clover

Mr. Isham J. Dorsey of Opelika, Alabama, uses a Phelps harvester for gathering Manganese Bur Clover seed. Mr. Dorsey says of this machine:

> We have tried to use this harvester to gather Crimson clover seed, but with no success. However,

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[5] W. H. Sheldon and S. T. Dexter, "Harvesting Ladino Clover Seed with a Vacuum Harvester," The Quarterly Bulletin, Vol. 31, No. 2, published by Michigan State College Agricultural Experiment Station (East Lansing, Mich., Nov. 1948), 215-218.

[6] Ibid. In reply to the author's letter inquiring about vacuum harvesters for crimson clover, Mr. Walter M. Carlston, Associate Professor of Engineering, wrote: "We have used several different methods of harvesting ladino seed and I think the information is directly applicable to crimson clover. Unfortunately, I do not know of any commercial vacuum harvesters for this type of work." Personal letter from Walter M. Carlston, Associate Professor, Department of Agricultural Engineering, Michigan State College, June 27, 1951.

> We feel that the fault was ours in that we had allowed the Crimson Clover field to get too weedy. In using this Phelps harvester, we mow the field first and then suck up the litter along with the seed. This litter is later cleaned out with a machine of our own making.[7]

Mr. T. N. Jones, Agricultural Engineer, Mississippi Agricultural Experiment Station, State College, Mississippi, has this to say of suction devices:

> A large number of such devices are used in Mississippi for harvesting burr clover. These machines usually consist of a cotton gin fan with approximately a 3½ to 4 ft. narrow open suction pipe powered by either tractor or gasoline engine and blowing the seed into a screened frame on a trailer.[8]

<u>Buffalo Grass</u>

A vacuum harvester similar to those discussed above was designed by Frank J. Zink, at Kansas State College, under the auspices of the U. S. Soil Conservation Service, for collecting buffalo grass seed. "In design this machine resembled an oversize vacuum cleaner.... . A self-contained unit with its own power plant was designed," which could

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7 Personal letter from Isham J. Dorsey, Opelika, Alabama, June 27, 1951. The author sent out a number of letters of inquiry to try to locate vacuum-type harvesters which might be at present in operation in harvesting crimson clover. In their replies the following people stated that they had no knowledge of machines of this type: Mr. S. E. Gissendanner, Superintendent of Sand Mountain Substation, Crossville, Alabama; Mr. R. M. Reaves, District Agent, Cooperative Extension Work, Auburn, Alabama; Mr. Fred Stewart, Superintendent, Tennessee Valley Substation, Belle Mina, Alabama.

8 Personal letter from T. N. Jones, State College, Mississippi, November 3, 1950.

easily be towed by a light motor truck to widely separated areas. "Seed and other material were collected with an ordinary feed-grinder dust collector and bagger." The efficiency of this machine on medium-length turf ranged from 66 to 68 percent; when the turf was clipped to 1 inch, the efficiency was increased from 10 to 40 percent.[9]

L. C. Aicher, superintendent of the Fort Hays Experiment Station at Hays, Kansas, under the auspices of the U. S. Soil Conservation Service, also developed a vacuum harvester for collecting buffalo grass seed. "This machine was mounted upon a four-wheel trailer with pneumatic tires; powered by a four-cylinder motor of 20 horsepower, and equipped with automobile transmission for operation of the fan." When the turf was clipped to one inch, the efficiency of this machine was increased from 48 to 95 percent.[10]

Subterranean Clover

A trailer-mounted suction harvester for subterranean clover seed was designed in 1945 by R. Lunde of Oregon State College. This harvester was equipped with four pick-up heads of the constant area type. The intake opening of each head was 19-1/2 by 2 inches. Skirts 3 inches in

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[9] Frank F. Zink, "Design of a Machine for Harvesting Buffalo Grass Seed," Agricultural Engineering, XVII (May 1936), 197-8.

[10] Guy C. Fuller, "Harvesting Native Grass Seed," Agricultural Engineering, XVII (May 1936), 195-197.

width were used at the front and rear of the openings. Mr. Lunde's tests indicated that the skirts are essential for good elevating efficiency. The air stream for this unit is furnished by a Phelps standard weight, Model H, size 35-inch cotton unloader fan, equipped with a 6-inch wide blast wheel instead of the 4-inch wheel with which it is regularly furnished. The blast wheel in this fan is the Rembert type (single inlet paddle-wheel type with rotating perforated shield covering the intake side of the wheel). Mr. Lunde found that ordinary paddle-wheel fans cracked a large percentage of the seed picked up while the Rembert type did not. A power unit capable of delivering 20 H.P. continuously is required for the fan. Mr. Lunde's report contains the following conclusions:

> In using the suction harvester, we find it necessary to remove, insofar as possible, all straw and other material left from the initial harvesting operation. . . . . This type of suction machine has been found to be very satisfactory in picking up subterranean clover seeds still in the burr, when the stubble is short and all loose straw has been previously removed as cleanly as possible. There is little evidence that this machine will pick up fine seeds which have shattered, particularly if there is any stubble left.[11]

A number of these machines have been built in the North-

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11 General Specification for Subterranean Clover Seed Suction Harvester to accompany Plan No. 10.1, prepared by R. N. Lunde, Agricultural Engineering Department, Agricultural Experiment Station, Oregon State College, Corvallis, Oregon, Dec. 1945.

west and have proved to be fairly successful. One man, however, who tried to incorporate the idea with a combine, found that the unit was entirely too cumbersome.[12]

Crimson Clover

A few years ago Mr. Thomas Hutchinson of Murfreesboro, Tennessee, built a vacuum attachment for an Allis-Chalmers combine for the purpose of harvesting crimson clover. His machine consisted essentially of one 6-foot wide suction head mounted directly behind the cutter bar of the combine and a home-made fan powered from the combine cylinder shaft. The material collected by his unit was discharged directly into the conveying draper of the combine. Mr. Hutchinson reported that the machine worked fairly well but that it has since been discarded in favor of combining straight from the windrow.[13]

Summary of Pertinent Design Information

After making a thorough survey of all available literature on pneumatic harvesting machines and inquiring through personal interview and by personal letter for further information in regard to machines of this kind which

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[12] Personal letter from R. N. Lunde, June 22, 1951.

[13] Statement by Mr. Thomas Hutchinson, personal interview, Dec. 28, 1950; May 25, 1951.

have been used in the past and/or are in operation in the present time, the author has arrived at the following conclusions: For those units which have proved to be successful, the power requirements were very high. The conventional paddle-wheel type of fan was used successfully on most of the machines; only one designer reported seed damage resulting from the use of this type of fan. The pick-up heads should be of the constant-area type. The shape of the intake openings of the pick-up heads is still questionable. For the most efficient operation of a vacuum harvester the stubble should be as short as possible.

CHAPTER III

DESIGN OF THE PICK-UP ATTACHMENT

Determination of the Criteria for the Design

In searching for an efficient method of harvesting crimson clover seed, the process under consideration was that of capturing shattered seed from the ground during the combine harvesting operation. It seemed feasible that an attachment for a combine would be the answer to the problem. The attachment was regarded essentially as an industrial exhaust system adapted to the particular needs of this process. The characteristics which in the opinion of the author should be incorporated in the design are as follows:

1. The attachment should not require special attention of the operator during the operation.

2. The power requirement of the attachment should be as low as possible.

3. The suspension system of the pick-up heads should be flexible to allow them to follow the contour of the ground.

4. The point of operation for the pick-up heads should be between the cutter bar and the straw discharge opening of the combine to eliminate rehandling of the straw.

5. The ground clearance of the pick-up heads should be constant.

6. The attachment should be adaptable for all popular makes of combines.

7. The unit should be economical to operate and priced low enough to be within the purchasing range of the seed growers.

8. The entire unit should be compact and easy to manipulate.

Not all of these features, however, were incorporated in the design of the experimental model, for it was decided that this model should be designed primarily to determine the requirements of the unit in the field.

For convenience in testing, the unit was designed for attachment to the rear of an Allis-Chalmers "60" All-Crop Harvester since this combine discharges straw to the side rather than to the rear and provides a clean stubble area which is very accessible.

After selecting the combine, measurements were made to determine the amount of space available for the attachment. It was decided that the pick-up heads should be attached to the rear of the combine and in line with the cutter bar. This placement of the heads was advantageous in that they could be easily adjusted and observed in the field, and the main air duct leading from the heads to the fan would contain a length of straight duct in which velocity pressure readings could be taken with a sufficient degree of accuracy.

It was decided, however, that once the requirements of the system are confirmed by field test the attachment should be redesigned to attach near the main axle of the combine where the vertical motion of the combine relative to the ground would be lessened appreciably.

Since the clearance between the ground and the pick-up heads was considered to be important in testing, it was decided that four individually suspended pick-up heads should be used for an accurate maintenance of this clearance.

Selection of the Minimum Control Velocity

The minimum control velocity is the air velocity which must be created at the source of shattered seed to collect and air float the seed.

The control velocity for a conveying system depends on both the diameter of an equivalent cross-section of the individual particles and the bulk weight of the material to be conveyed.[1] The diameter of an equivalent cross section was estimated to be 1/10 of an inch, and the bulk weight was estimated to be 5.62 pounds per cubic foot of material based on weights and ratios published by E. A. Hollowell.[2] By using calculations, the control velocity was found to be about 2000 ft. per min. (See calculations, Appendix A.)

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1 Fan Engineering (Buffalo, 1948), ed. by Richard D. Madison, p. 614.

2 Hollowell, op. cit.

Pick-up Heads

A pick-up head with a ground clearance of 1/2 to 3/4 of an inch was chosen. This ground clearance required 250 cubic feet of air flow per minute to maintain an average velocity of 2000 ft. per minute at the pick-up head opening. Therefore, a total of 1000 cubic feet of air per minute was required for the four heads.

A duct velocity of 2500 feet per minute was chosen upon the basis of recommendations published by Allen D. Brant.[3] The general shape of the pick-up heads was based on design recommendations for a suction-type filbert harvester published by R. N. Lunde.[4] (See Fig. 1, 2, 3.)

An opening of 1 by 13¼ inches was chosen for the pick-up head entrance. The lower section of the pick-up head was constructed of 1/8-inch sheet metal to reduce warpage during fabrication. The openings to t he heads were rounded by brazing one-inch pipes tangent to the front and rear edges of the openings. The openings of two of the heads were further altered by adding 1-1/2 inch flanges, or skirts, horizontal to the ground. These flanges were curved with a 1/2-inch radius at both the inner and outer edges for

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2 Hollowell, op. cit.

3 Brandt, Allen D. "Heating and Ventilating," A Summary of Design Data for Exhaust Systems, XLII (May 1945), 74-88.

4 R. N. Lunde, Design for a Suction-Type Filbert Harvester, Ore. Agr. Exp. Sta. Tech. Bul. No. 14 (Carvallis, Ore 1948).

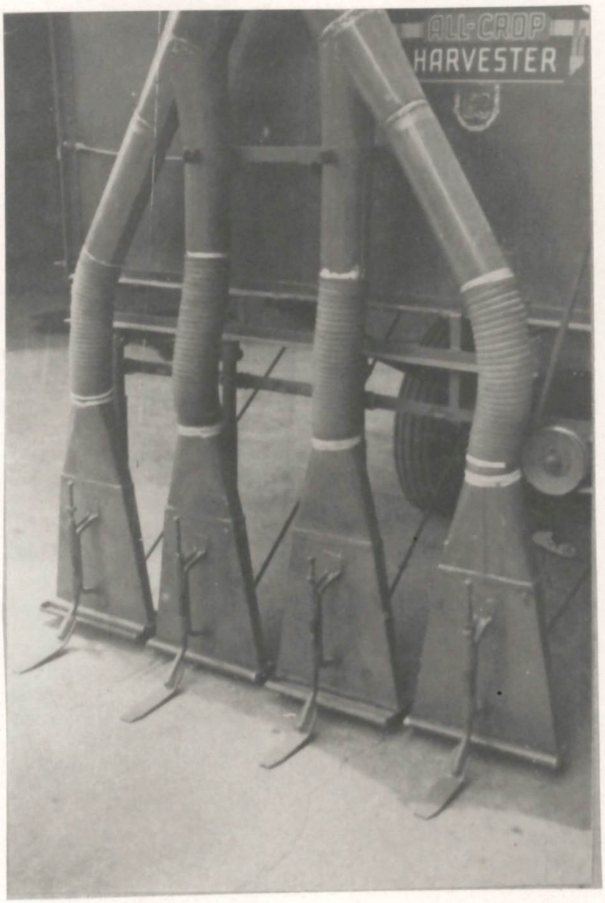

Figure 1. Two Types of Pick-up Heads

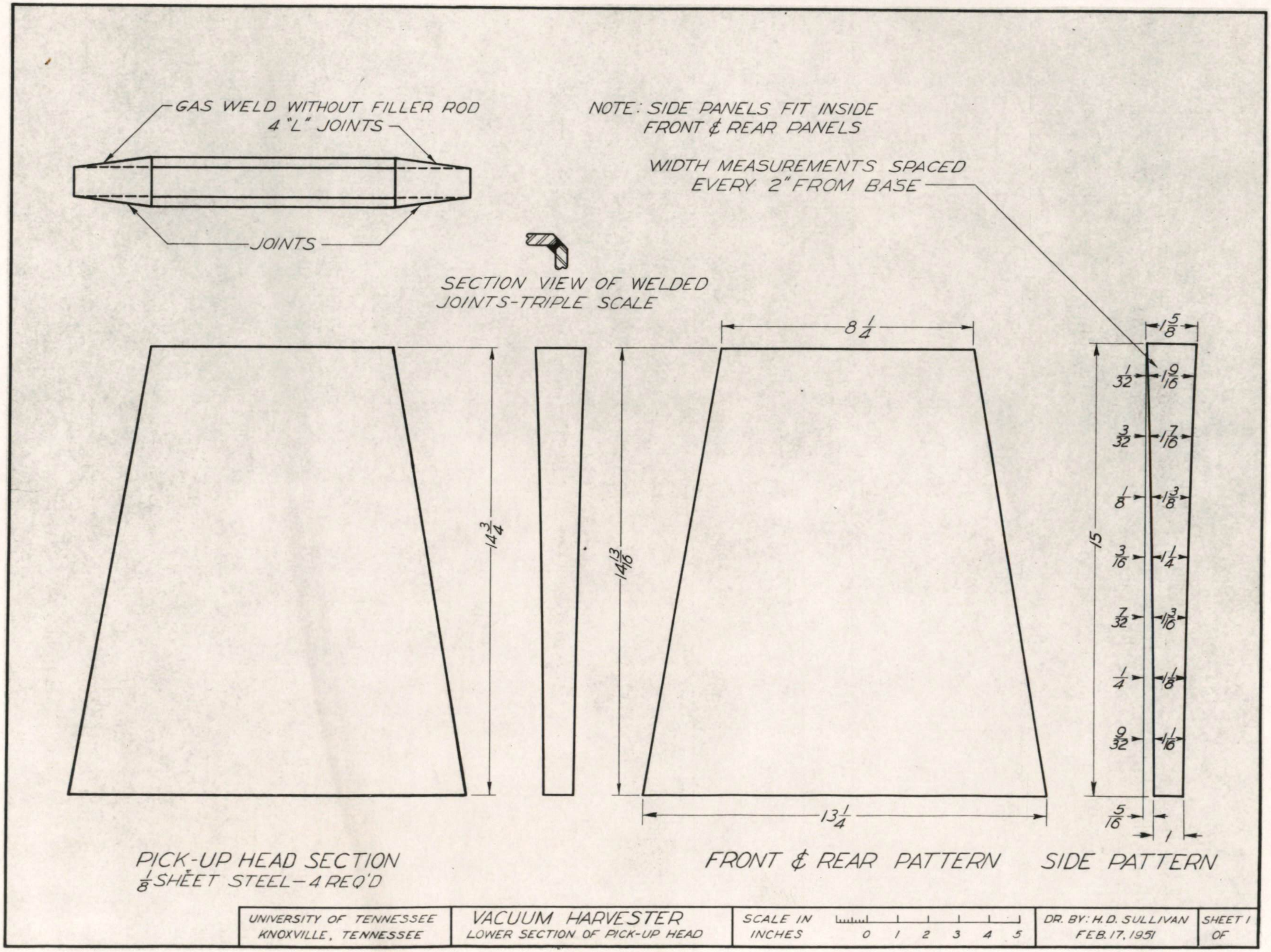

Figure 2. Lower Section of Pick-up Head

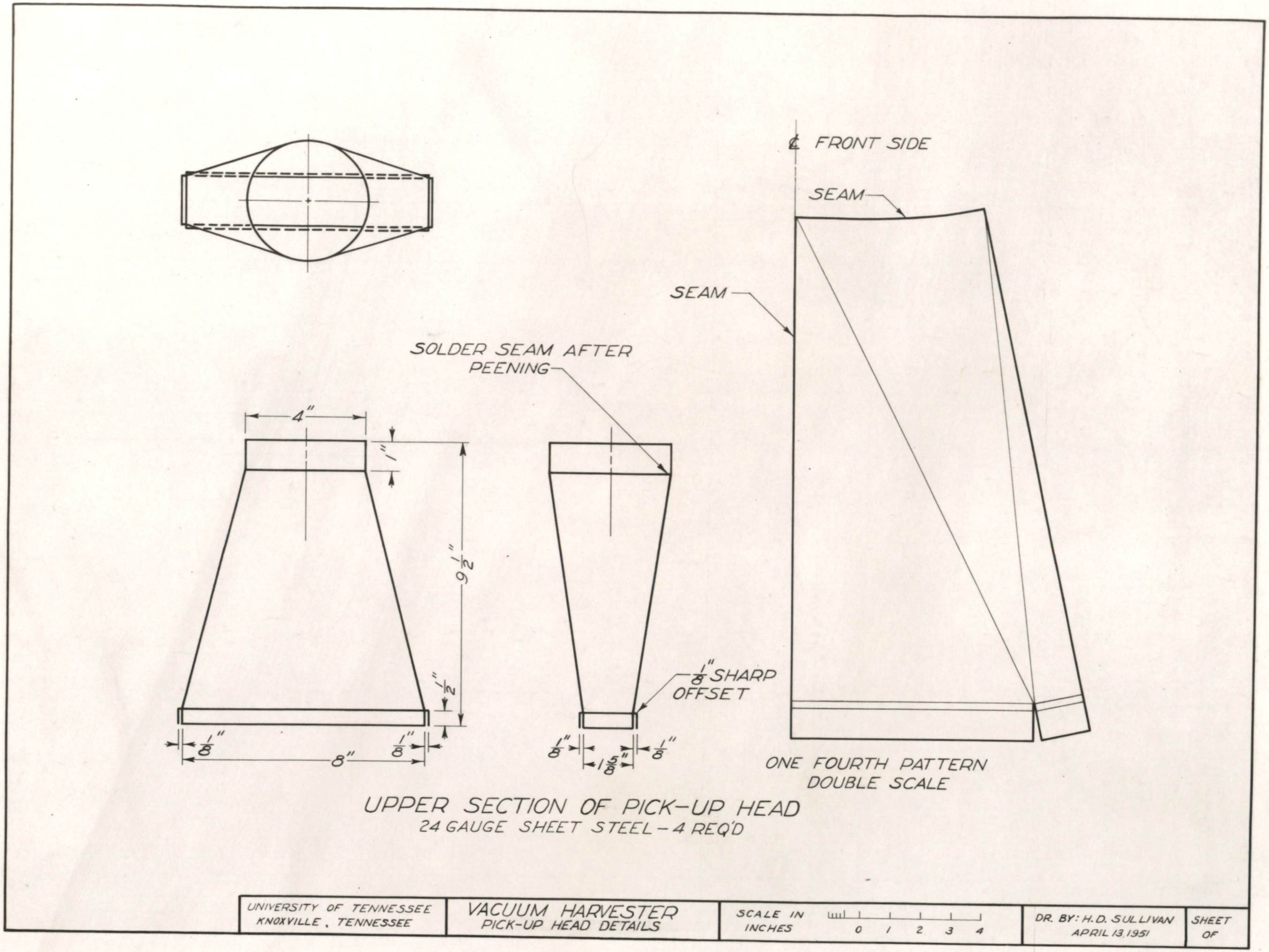

Figure 3. Upper Section of Pick-up Head

efficient air flow.

Suspension System

The suspension system was designed to allow the pick-up heads to follow the contour of the ground while remaining in a vertical position. This end was attained by mounting the heads on simple telescoping members, which were pivoted to the rear of the combine. The telescoping members were made free to rotate to the rear from a vertical position, allowing the heads to pass over very large stones and other obstructions which might otherwise cause considerable damage. An adjustable castor skid was used to support each head and maintain the proper ground clearance. The drag force of the skid on the ground was counter-balanced by tension springs acting straight forward. (See Fig. 4.)

Fan Design

Fan companies[5] were consulted in regard to the selection of a suitable fan to meet the air requirements of the system, but the cost of the commercial-type fans recommended could not be justified by the purpose. The fans available for use by the Agricultural Engineering Department were equipped with shrouded runners which made them unsuitable for handling straw. Consequently, the design and

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5 Buffalo Forge Co. Clarage, Aerovent.

Figure 4. Suspension System

construction of a special fan was necessary.

One of the shrouded-runner-type centrifugal fans tested in the laboratory delivered 1000 cu. ft. of air per minute, with a static pressure of 2 inches water gage at the fan intake when operated at 1650 r.p.m. Since this performance was satisfactory for the system, the over-all dimensions of the runner and scroll case of this fan were adopted. The cost of a belt drive and of a fan mounting, including a shaft and bearings, was saved by mounting the fan runner directly on the end of the combine cylinder shaft, which turns 1650 r.p.m. when harvesting crimson clover seed. The scroll case mounting consisted of two pieces of angle iron bolted to the rear of the case and drilled to fit the four cylinder-clearance adjustment bolts, which are always in the same position relative to the protruding cylinder shaft. (See fig. 5, 6, 7, 8 and Appendix B.)

Piping System

The piping to convey the material from the pick-up heads to the threshing cylinder of the combine was designed for minimum turbulence and pressure loss. An air velocity of 2500 feet per minute was chosen for conveying the material through the piping.[6] The flexible hose, 4 inches in diameter

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[6] The selection of this velocity was based on recommendations published by Allen D. Brant, "Heating and Ventilating," May 1945.

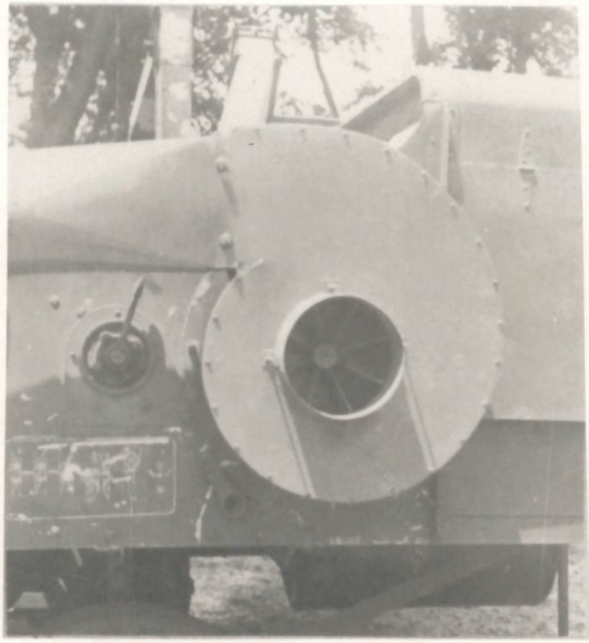

Figure 5. Assembled Fan

Figure 6. Fan with Cover Removed

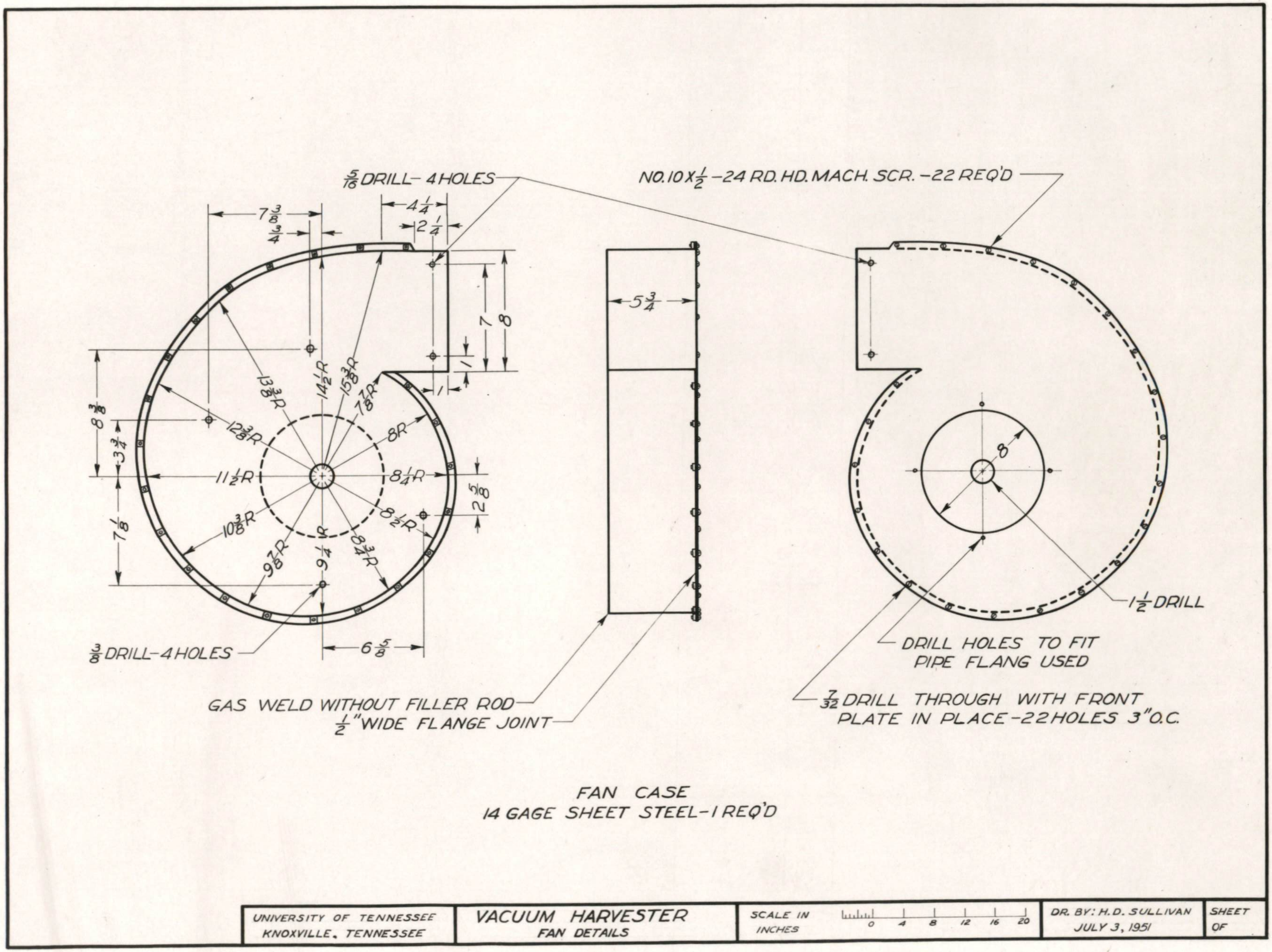

Figure 7. Fan Case Construction

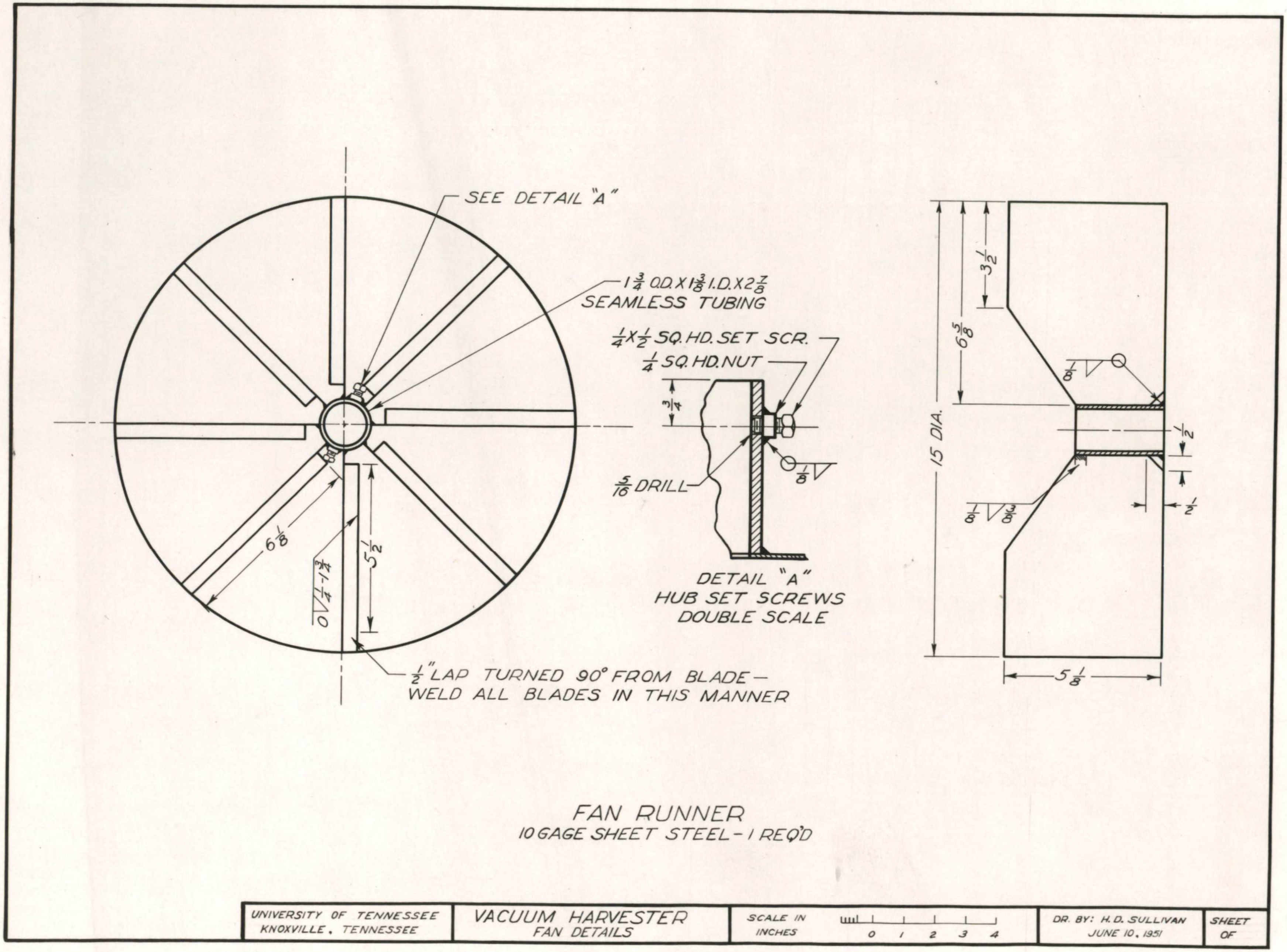

Figure 8. Fan Runner Construction

by 19 inches in length, used on the ventilation systems of 1949 and 1950 models of Cadillac automobiles was selected to connect the pick-up heads to 4-inch diameter ducts. The hose was made of a spiral metal reinforcement strip with the space between the spiral loops covered with a light-weight rubber-impregnated fabric. This type of construction was preferred to the conventional wire spiral and fabric sheath type because of its greater flexibility and smoother contour when bent.

It was decided that the piping from the heads should converge into one main pipe as quickly as possible to avoid the higher friction loss encountered in smaller ducts. A "Y" branch was designed to direct the air streams of the four 4-inch diameter pipes into one main 8-inch diameter pipe. (See Fig. 9, 10, 11.) The cross sectional areas of the transitions used in this branch were made very nearly constant in order that the velocity throughout the branch would be constant. The entire branch was constructed as one piece and mounted rigidly in a vertical position on the rear of the combine. The remainder of the intake piping consisted of an 8-inch diameter duct made up of three long-radius elbows and one straight run of pipe. A radius ratio (ratio of the radius of turn of the centerline to the diameter of the duct) of 2.5 was selected for all turns used in the system, giving a pressure loss equivalent to only 14 percent

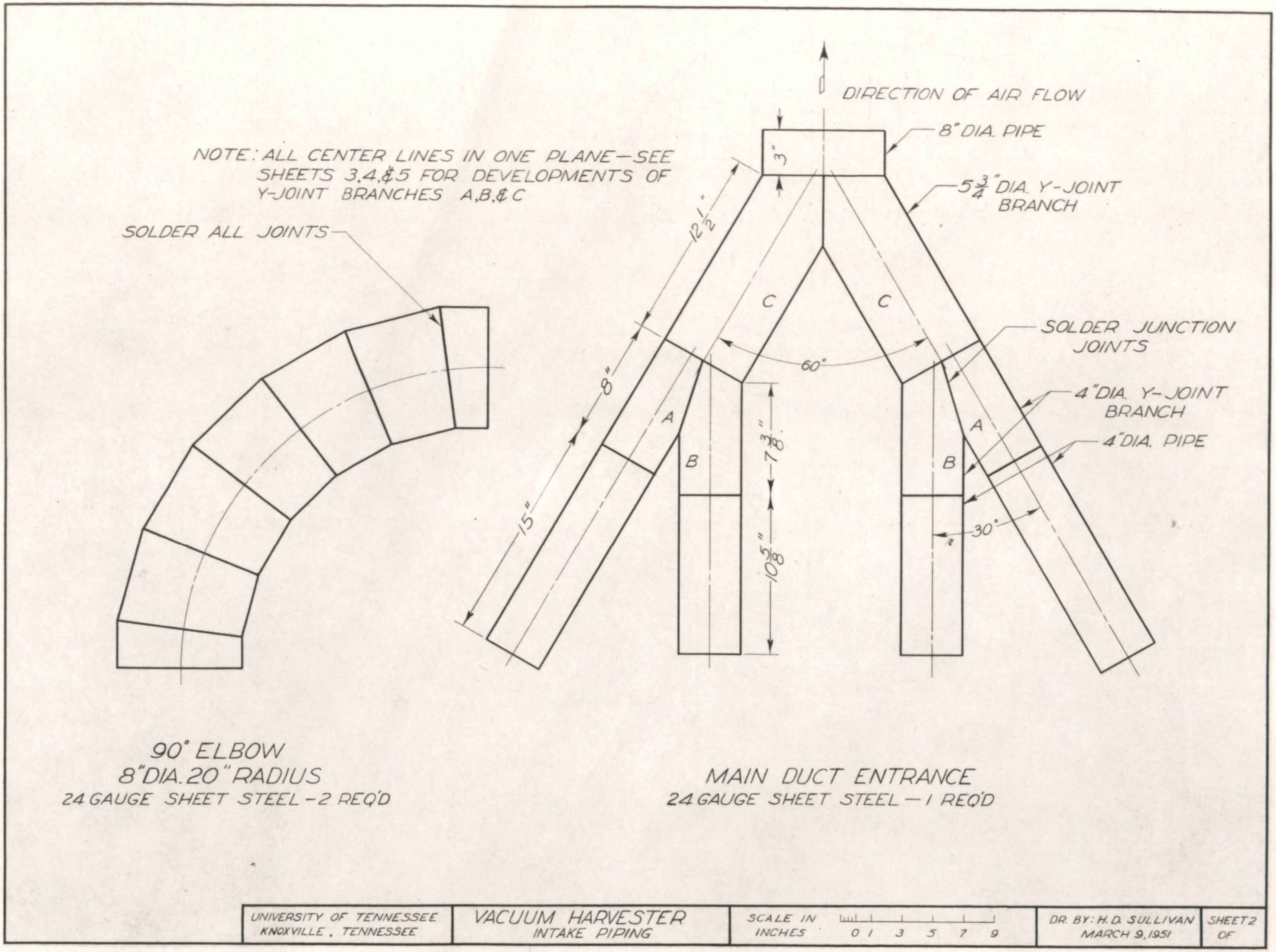

Figure 9. "Y" Branch and Elbow Construction

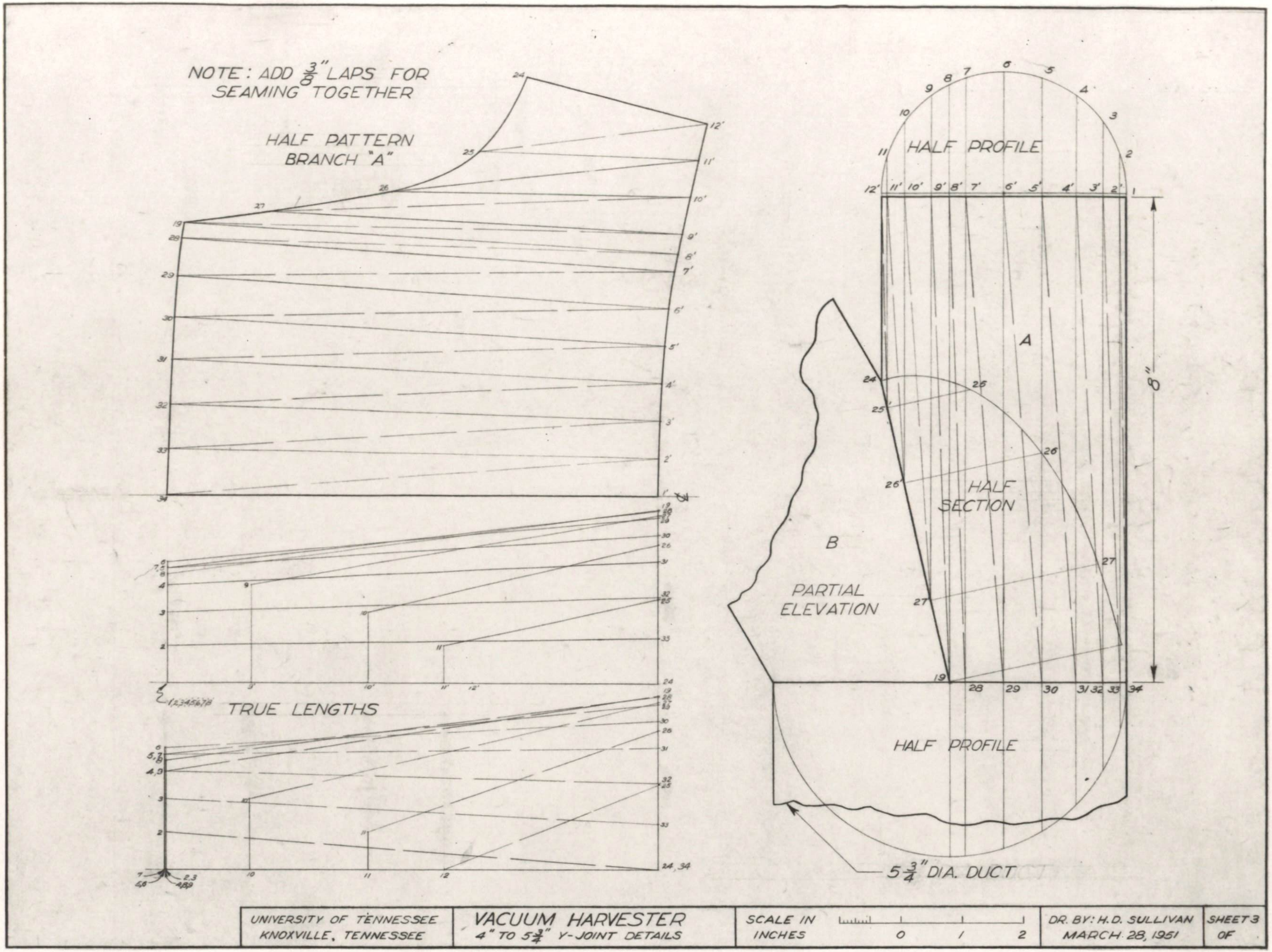

Figure 10. Pattern Construction for "Y" Branch Sections

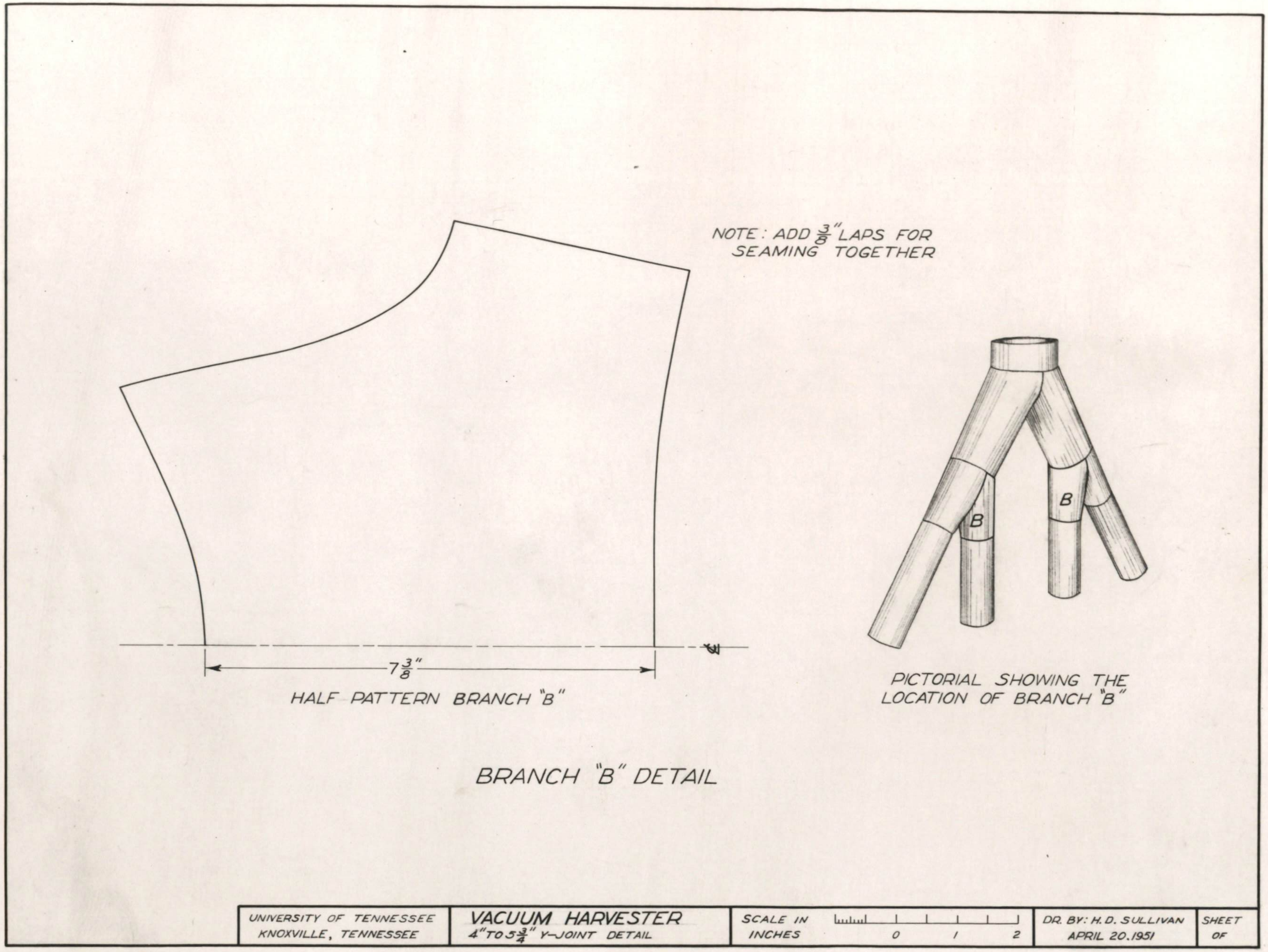

Figure 11. Simplified Pattern Layout for "Y" Branch Section

of the existing velocity pressure.[7] A tripod type of support for the main duct was designed to prevent excess vibration and to support the weight of the duct. The legs of this support were designed to fit under the heads of bolts already existing on the top of the combine. (See Fig. 12.)

Discharge Duct

The function of the discharge duct is to convey the material from the fan to the threshing cylinder of the combine. The convenient location of the fan made the design of this duct relatively simple. A 180 degree-long-radius turn was used to direct the material around the side of the combine's inclined header. The open end of the discharge duct was centered between the upper and lower drapers of the combine in order that the stream of air and material discharged would be in line with the feed opening which leads to the threshing cylinder. The open end of the turn was supported by a simple beam and yoke arrangement which permitted freedom of movement of the upper draper frame. (See Fig. 13.)

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[7] Fan Engineering, p. 149.

Figure 12. Main Duct Support

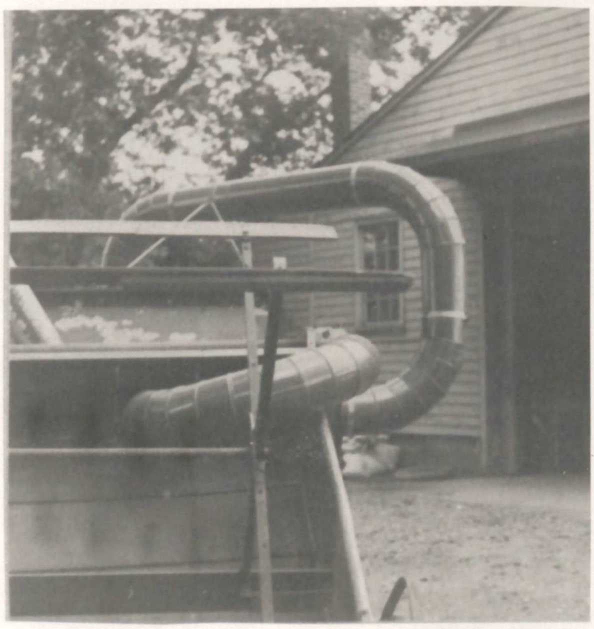

Figure 13. Discharge Duct

CHAPTER IV

THE TESTING

The Laboratory Tests

The laboratory test of the attachment was set up on a concrete floor in such a way as to simulate as nearly as possible actual field conditions, with the exception of the irregularities of the ground surface and the presence of stubble. The temperature of the air during the test was approximately 82° F. Clover seed which had been hand-stripped from this year's crop was spread over an area 2 by 6 feet. The attachment was mounted on an Allis-Chalmers "60" All-Crop Harvester with the harvester cylinder speed adjusted to 1600 revolutions per minute. This speed gave an air velocity pressure of 1/2 inch, which is equivalent to 2800 feet per minute, and a static pressure of minus 2 inches water gage through the main duct. The air velocity and static pressure readings were taken with a pitot tube and a U-tube type water-filled manometer.

To allow the machine to attain the proper speed before passing over the seed, the combine was started 40 feet from the seed area. The clearance between the pick-up heads and the floor was adjusted to different heights ranging from 1-1/2 inches to 1/2 inch. The test showed that at a clearance of 3/4 of an inch or less the pick-up heads picked up all the seeds.

Two of the pick-up heads were equipped with plain, rounded-entrance lips, the rounded edges of which were constructed of pipe 1 inch in diameter. The other two heads were equipped with flange-type entrance lips 1-1/2 inches wide, with 1/2 inch-radius turns at the outer and inner edges. (See Fig. 1.) The laboratory test indicated no significant difference in the efficiency of the two types of pick-up head entrances.

The static pressure measured at the junction point of the pick-up head and flexible piping was 1-inch water gage for both types of heads tested. The static pressure measured at the edge of the entrance lips was minus 1/4 inch water gage.

A similar test was then conducted on an irregular surface, a gravelled driveway with gravels ranging in size from 1 inch in diameter to sand and loam. The pick-up heads, at 3/4 of an inch clearance picked up approximately 90 percent of the seed. A small amount of dust and pebbles of about 1/8 of an inch in diameter were picked up with the seed.

The Field Tests

Conditions of the Test Plot for the First Test

In the first field test made of the machine the clover plot available was representative of adverse field conditions. The plot was located on fertile river bottom land. The high fertility of the soil had promoted an abundant plant growth and almost complete lodging of the crop prior to the bloom stage. At the time of maturity of the seed crop the stems were in a mat 3 or 4 inches deep with the heads at the end of the stems turned up a few inches in a vertical position. (See Fig. 14.)

<u>The First Test</u>

The purpose of the first test was primarily to study the operation of the pick-up head suspension system under field conditions.

One of the castor skids failed to turn when the combine was moved in a reverse direction. The added force of the reversed skid caused the slide stop to fail in bending but did not damage any of the other parts. The slide stop was removed and straightened before the test was continued. The slide-spring tension, which had been sufficient under laboratory conditions, was not great enough to keep the slides against the slide stop. This was adjusted.

The combine cutter bar equipped with pick-up guards was lowered as much as possible without creating an excessive drag on the combine. Even at this level the combine removed only about one-third of the plant material. The remaining

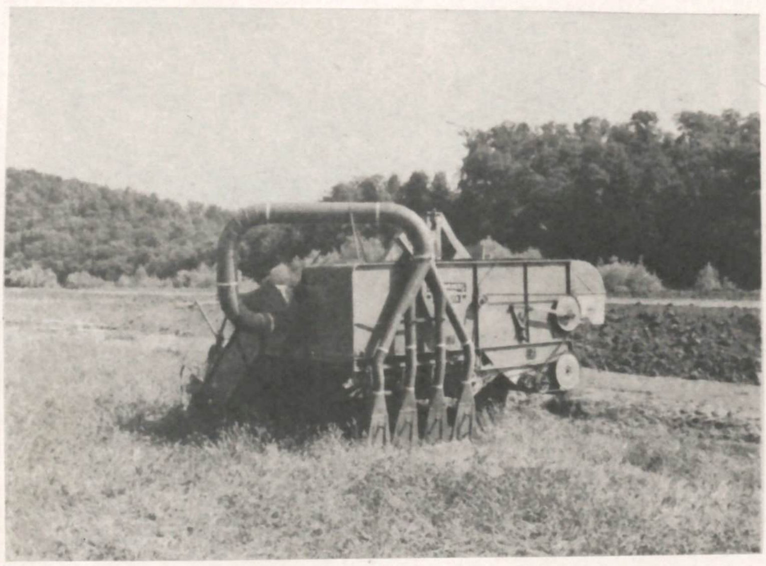

Figure 14. View of Test Plot and Harvesting Equipment

two-thirds of the plant material was left on the ground in the form of a loose mat about 3 inches in depth.

At the time of the first field test the shattered seed loss was approximately 5 percent and the shattered seeds were on the ground below the mat formed by the long stubble. The air stream at the pick-up heads was not effective in capturing a significant amount of these shattered seeds and in elevating them through the stubble. It was decided that the shape of the intake openings should be changed by adding flange-type entrance lips and that a test of the pick-up efficiency of the unit should be made at a later date when the loss due to shattering was greater.

Conditions of the Test Plot for the Second Test

Inclement weather conditions following the first field test prevented further testing for a period of one week. The daily showers during that time increased the shatter loss of the crop to about 40 percent and caused further lodging of the crop. The mat of plant material on the plot was further packed by the showers, and the seed heads did not protrude as far above the mat as they had during the first test.

The Second Test

The purpose of the second test was to obtain data for determining the relative efficiencies of the two types of pick-up heads[1] and of the combine when functioning without the pick-up attachment.

The discharge turn was removed from the machine, and a large burlap bag to catch the material discharged from the fan was attached to the discharge opening. The two pick-up heads which were equipped with rounded entrances were attached to the combine, and the ground clearance was set at 1 inch. The two remaining 4-inch diameter branch ducts were plugged. The cylinder speed was adjusted to 1650 r.p.m. to give a velocity of approximately 2000 feet per minute in the main duct. The velocity at the pick-up head opening could not be determined accurately, since the area under each head was constantly varying, depending on the amount and density of stubble. It was, however, estimated to be 2000 feet per minute.

A 325-foot length of travel was laid off in the test plot. This length was traveled once with the two rounded entrance heads in operation and once with the two flanged entrance heads in operation. The material picked up by the heads was collected for each run and labeled for comparative analysis later. The tractor operator was instructed to get

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[1] An additional pick-up head was constructed without flanges or turns at the intake opening. However, since this head gathered too much loose material on the edges of the opening, it was discarded as unsatisfactory before the second field test.

as much seed as possible with the header of the combine during both runs, plus an additional run. This seed, which was representative of the yield if the plot had been harvested in the conventional manner, was also collected and labeled.

The combine header clipped the seed heads that were protruding from the mat of straw but left the bulk of the plant material on the ground. The clover, which had decayed considerably at the time of the second test, was broken loose at the ground by the drag force of the cutter bar. This loose material built up to a depth of 6 to 8 inches, causing the pick-up heads to rotate to the rear. This action allowed the lump to pass under the pick-up heads, but more loose material was collected as soon as the heads returned to a vertical position. The alternate raking and dumping action of the heads caused them to stay out of the proper operating positions at least 50 percent of the time.

After weighing the samples of material collected by the pick-up heads, the hulled seeds were removed from each of the samples with a "clipper" seed cleaner. The unhulled seeds and foreign matter salvaged from this cleaning operation were threshed with an Allis-Chalmers "40" All-Crop Harvester. To determine the threshing effect of the fan, the seed sample weights obtained from these two operations were compared.

(See Table I.) The total seed yields from the pick-up heads were also compared with the seed yield from the combine. (See Table II.)

TABLE I

THRESHING EFFECT OF THE FAN

Pick-up Head Type	Bulk Material Collected	Hulled Seed Removed by Cleaner	Seed Removed by "40" Harvester	% Threshing by Fan
Flanged	9.7	0.7	0.21	76.9
Rounded	12.1	0.61	0.21	74.4

[a] All weights are in pounds.

TABLE II

COMPARISON OF YIELDS OBTAINED IN THE SECOND FIELD TEST

Collector	Acres Area Covered	Pounds of Seed[a] Harvested	Pounds of Seed per Acre
Combine Header	0.134	2.17	16.2
Flanged Lip Pick-up Heads	0.0224	0.91	40.65
Rounded Lip Pick-up Heads	0.0224	0.82	36.6

[a] Weights are for recleaned seed.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

The findings of this study indicate that a pneumatic pick-up attachment for combines can be used to an advantage during the crimson clover harvesting operation. The field tests, even though not sufficient in number to be definitely conclusive, indicate that the design of the experimental attachment is satisfactory from the standpoint of convenience and economy. In the opinion of the author, however, some changes in the design would improve the performance of the attachment. The ground clearance should be increased. In order to do this properly, the unit should be increased throughout to handle 2000 cubic feet of air per minute at a velocity of 2000 feet per minute. A parallel four bar linkage type of suspension system should be used, which would force the pick-up heads to be constantly in a position perpendicular to the ground.

Further investigations should be made to determine the following: (1) the most efficient shape for the pick-up head lips; (2) the air velocity needed at the intake openings under several different field conditions; (3) the increase in yield attributed to the use of the attachment, based on tests conducted over several acres.

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APPENDIXES

APPENDIX A

AIR REQUIREMENT CALCULATIONS

Control Velocity at Pick-up Heads

Known Values

(1) Weight of the material to be conveyed ... 5.62 lb/cu.ft.

(2) Diameter of equivalent cross-section of the particles to be conveyed . . . . 0.1 inch.

Calculation of Control Velocity

$V = 1030 \sqrt[3]{W} \sqrt{d} + 582.5 \sqrt{W}$ [1]

Where V = air velocity, ft. per min.

W = bulk weight of material, lb. per cu. ft.

d = diameter of equivalent cross-section of the material to be conveyed, inches.

$V = 1030 \sqrt[3]{5.62} \sqrt{0.1} + 582.5 \sqrt{5.62}$

$V = 1945.3$, say 2000 ft./min.

Quantity of Air Required for the System

Known Values

(1) Length of each pick-up head . . . . . . 13.25 inches.

(2) Horizontal distance from opening to most remote source of material . . . . 0.4 inch (assumed).

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[1] Fan Engineering, p. 614.

Calculation of Air Quantity

$Q = K L W V$ [2]

Where Q = rate of flow, cu. ft. per min.

K = a constant equal to 1.5 for the case considered.

L = length of opening, feet.

W = width of table in feet (from opening to most remote source of material).

$Q = 1.5 \times 13.25/12 \times 0.4 \times 2000/12$

$Q = 110$, say 125 cu. ft. per min.

Static Pressure Required for the System

Known Value

Duct Velocity . . . . 2500 ft. per min. (based on recommendations by Brandt[3])

Hood Entrance Loss

Static pressure loss . . . . 2.50 velocity pressure.[4]

Flexible Duct Loss

The flexible duct was tested in the laboratory and found to have a loss of about 0.2 velocity pressure.

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[2] Allen D. Brandt, "Heating and Ventilating".

[3] Ibid.

[4] Laboratory Test.

Four-Inch Diameter Metal Duct Loss

Friction loss in inches of water per 100 ft. is 3.5; therefore, the pressure loss for a 15 inch length is equal to 0.044 inches of water.

Two "Y" Branch Transformations Loss

Pressure loss in each transformation is 0.1 vel. pressure.[5]

Pressure loss for 2 transformations is 0.2 vel. pressure.

Loss in Eight-Inch Elbows on Intake Side of Fan

The loss per elbow equals 0.14 velocity pressure.[6]

The loss for 3 elbows equals 0.42 velocity pressure.

Loss in Five-Foot, Straight, Eight-Inch Diameter Duct

Loss per 100 feet of 8 inch diameter duct is 1.5 inches of water.

The loss per 5 feet of duct is 0.075 inches of water.

Total Static Pressure Required

1.0 + 0.08 + 0.044 + 0.08 + 0.168 + 0.03 equals 1.402 inches of water.

This value should be raised to 2 inches to allow for incorrect assumptions and other factors which may have caused errors.

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5 *Fan Engineering*, p. 158.

6 *Ibid.*, p. 149.

APPENDIX B

FAN CALCULATIONS

Known Values

(1) Fan Speed . . . . 1650 r.p.m.

(2) Quantity of Air . . . . 1000 cu. ft./min.

(3) Static Pressure . . . . 2 inches of water

Specific Speed of Fan

$$N_s = \frac{rpm \sqrt{cfm}}{(P_s)^{3/4}}$$

Where N_s = Specific Speed

rpm = rev. per min. of fan

cfm = cubic feet per minute of fan

P_s = static pressure of fan in inches of water

$$N_s = \frac{1650 \sqrt{1000}}{(2)^{3/4}}$$

$$N_s = 31{,}000$$

Static Efficiency

The static efficiency of a straight blade fan for a specific speed of 31,000 is 66 percent.[7]

Fan Horsepower

$$hp = \frac{0.000157 \times cfm \times \text{static pressure in inches}}{\text{static efficiency}}$$

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[7] Fan Engineering, p. 246.

$$hp = \frac{0.000157 \times 1000 \times 2}{0.66}$$

$$hp = 0.475$$