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PRELIMINARY TESTS OF BLOWERS OF THREE DESIGNS OPERATING IN CONJUNCTION WITH A WING-DUCT COOLING SYSTEM FOR RADIAL ENGINES

By David Biermann and E. Floyd Valentine
Langley Memorial Aeronautical Laboratory

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PRELIMINARY TESTS OF BLOWERS OF THREE DESIGNS OPERATING IN CONJUNCTION WITH A WING-DUCT COOLING SYSTEM FOR RADIAL ENGINES

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SUMMARY

This paper is one of several dealing with methods intended to reduce the drag of present-day radial engine installations and improve the cooling at zero and low air speeds. The present paper describes model wind-tunnel tests of blowers of three designs tested in conjunction with a wing-nacelle combination. The principle of operation involved consists of drawing cooling air into ducts located in the wing root at the point of maximum slipstream velocity, passing the air through the engine baffles from rear to front, and exhausting the air through an annular slot located between the propeller and the engine with the aid of a blower mounted on the spinner. The test apparatus consisted essentially of a stub wing having a 5-foot chord and a 15-foot span, an engine nacelle of 20 inches diameter enclosing a 25-horsepower electric motor, and three blowers mounted on propeller spinners. Two of the blowers utilize centrifugal force while the other uses the lift from airfoils to force the air out radially through the exit slot.

Maximum efficiencies of over 70 percent were obtained for the system as a whole. Pressures were measured over the entire flight range which were in excess of those necessary to cool present-day engines. The results indicated that blowers mounted on propeller spinners could be built sufficiently powerful and efficient to warrant their use as the only, or chief, means of forcing air through the cooling system, so that cooling would be independent of the speed of the airplane.

INTRODUCTION

The development of airplanes capable of flying at speeds over 300 miles per hour has focused attention upon the drag due to radial engine installations. Enclosing the engines completely in streamlined nacelles, fuselage, or wing is a method for reducing or eliminating the form drag due to the engine, but the existing method for cooling must be altered to meet the conditions. Also, the problem of cooling engines of over 1,000 horsepower with the conventional N.A.C.A. cowling is quite serious at the present time for the low-speed conditions of flight or on the ground, because the quantity of air necessary for cooling has increased nearly in proportion to the power while the means for producing the necessary pressure has not been materially improved.

A previous report (reference 1) described model tests of a radial engine cooling system which utilizes the propeller slipstream for creating pressure to cool the engine, particularly for the low-speed conditions of flight. The present report describes tests of a cooling system which utilizes a blower for augmenting or replacing the pressure produced by the propeller. Blowers have become of interest in the development of cooling systems because they offer considerable variety to the methods of installing engines and because they can be built to cool any type or size of engine, independent of the air speed or slipstream velocity.

The purpose of the present investigation is to determine the characteristics of several blowers suitable for cooling radial engines. The test program completed to date covers tests of several blowers built into propeller spinners. Several arrangements of entrance locations and direction of cooling air flow have been studied. This paper describes only the blower tests made with the wing-duct system described in reference 1. In a later report the results of tests of blowers operating in conjunction with side entrances, and also of a blower which draws the air in through the nose of a spinner, will be given.

APPARATUS AND METHODS

The tests described in this paper were made with the

same basic wing-nacelle combination used for the wing-duct cowling tests described in reference 1 except blowers mounted on spinners were incorporated. A photograph of the blower set-up in the tunnel is shown in figure 1, while figure 2 shows a sketch of the nacelle arrangement. Three blowers, designated as blowers 2, 3, and 4, were mounted on the rear faces of propeller spinners. Blowers 2 and 3 are of the centrifugal type, built much in the same way as centrifugal superchargers, while blower 4 utilizes airfoil blades to force the air in a radial direction.

Blower 2.- In figure 3 a sketch of the model blower is given. Attached to the propeller hub is a steel plate to which are fastened 12 radial blades and the sheet aluminum spinner. The blades are bent at the throat of the blower in order that the air may be scooped up with a minimum loss of energy. The air is exhausted out an annular slot in a rearward direction with a rotational component. A stationary wood ring forms one surface of the air passage through the blower. A small clearance is provided between the blades and the wood ring.

Preliminary tests indicated that guide vanes located at the exhaust slot were necessary to remove the rotational component of the exhaust air in order to increase the thrust from the blower. Twenty-four airfoils were therefore located near the exhaust slot and a sheet aluminum hoop was placed over them, as may be seen in the figure. Inasmuch as the guide vanes were built to fit the existing blower, the external contour of the nacelle with vanes in place was rather poor.

Blower 3.- Blower 3 (fig. 4) is identical to blower 2 except the active length of the blades is less and the area of the throat greater. This modification was made with the intention of improving the efficiency and also to make fabrication easier for an airplane installation.

Blower 4.- This blower (fig. 5) was designed with the view of obtaining high efficiencies, although the maximum pressure obtainable was known to be less than for the centrifugal type. Twenty-four R.A.F. 6 airfoils are fastened to the rear face of the spinner which act to force the air outwardly through the annular slot. The principle of operation is identical to that of a propeller except for the direction of air flow.

An attempt to control the flow through the blower was made by providing means for restricting the throat area, shown in the figure with dotted lines. The purpose of this was to reduce the active blade width rather than of imposing a restriction in the flow channel.

Test procedure.- The blower tests were made by holding the r.p.m. constant and increasing the tunnel speed in steps to about 100 miles per hour. The blower speed was then reduced in steps to zero. A number of preliminary tests were made to determine the effect of Reynolds Number obtained by changing the rotational speed. These tests indicated only small changes in the blower characteristics with changes in rotational speeds above 1,500 r.p.m. Below this value the characteristics changed somewhat with changes in speed.

SYMBOLS AND EQUATIONS

Wing duct system.-

Q, quantity of cooling air, in ft. per sec.

A_e, equivalent engine orifice area.

A_d, equivalent entrance orifice area.

$A_{(e+d)}$, equivalent entrance and engine orifice area.

A_c, projected area of the engine.

K_e, conductivity of engine, A_e/A_c,

$$\frac{Q}{A_c\sqrt{\frac{2\Delta p_e}{\rho}}}$$

K_d, conductivity of entrance duct, A_d/A_c,

$$\frac{Q}{A_c\sqrt{\frac{2\Delta p_d}{\rho}}}$$

K_t, total conductivity of entrance duct and engine, $\frac{A_{(e+d)}}{A_c}$,

$$\frac{Q}{A_c\sqrt{\frac{2\Delta p_t}{\rho}}}$$

$$\frac{1}{K_t^2} = \frac{1}{K_e^2} + \frac{1}{K_d^2}$$

Δp_e, pressure drop across engine, lb. per sq. ft.

Δp_d, pressure drop across entrance duct, lb. per sq. ft.

Δp_t, total pressure drop across entrance duct and engine, lb. per sq. ft.

$$\frac{K_d}{K_t} = \frac{1}{\sqrt{1 - \frac{\Delta p_e}{\Delta p_t}}}$$

$$\frac{K_d}{K_e} = \frac{K_d}{K_t}\sqrt{\frac{\Delta p_e}{\Delta p_t}}$$

ρ, the mass density of air, slugs per cu. ft.

$K_p = \frac{\Delta p_t}{\rho n^2 D^2}$, pressure coefficient with propeller.

n, rotational speed of propeller.

D, propeller diameter.

<u>Blower system</u>.-

$$K_{1t} = \frac{\Delta p_t}{\rho n^2 d^2}$$

$$K_2 = \frac{\text{power required by blower}}{\rho n^3 d^5}$$

$$K_3 = \frac{Q}{nd^3}$$

$$K_4 = \frac{\text{thrust of blower}}{\rho n^2 d^4}$$

$$\eta_t = \frac{K_{1t} K_3}{K_2 - \frac{V}{nd}\frac{K_4}{\eta}},$$ the efficiency of the system.

n, rotational speed of blower, r.p.s.

d, design diameter of blower, ft.

V, forward speed of airplane, ft. per sec.

η, propeller efficiency.

$$K_t = \frac{A_{(e+d)}}{A_c} = \frac{K_3 d^2}{A_c \sqrt{2K_{1t}}},$$ (conductivity in terms of blower coefficients).

$$A_{(e+d)} = \frac{K_3 d^2}{\sqrt{2K_{1t}}}$$

$$\frac{A_{(e+d)}}{d^2} = \frac{K_3}{\sqrt{2K_{1t}}}$$ (restriction constant).

RESULTS

An outline of the mechanics involved in the problem of cooling engines is given in reference 1 and will not be repeated here. A number of new coefficients are introduced here, however, to cover the blower characteristics. These nondimensional coefficients are defined as follows:

$$K_{1t} = \frac{\Delta p_t}{\rho n^2 d^2}$$

$$K_2 = \frac{\text{power required}}{\rho n^3 d^5}$$

$$K_3 = \frac{Q}{nd^3}$$

$$K_4 = \frac{\text{thrust of blower}}{\rho n^2 d^4}$$

and

$$\eta_t = \frac{K_{1_t} K_3}{K_2 - \frac{V}{nd}\frac{K_4}{\eta}}$$

The test values of K_{1_t}, K_2, K_3, K_4, and η_t are plotted against $\frac{V}{nd}$.

The total pressure drop across the engine and entrances (Δp_t) may be divided up into the pressure drop across the engine (Δp_e) and the pressure drop across the entrance ducts (Δp_d) according to the relations,

$$\frac{K_d}{K_t} = \frac{1}{\sqrt{1 - \frac{\Delta p_e}{\Delta p_t}}},$$

$$\frac{K_d}{K_e} = \frac{K_d}{K_t}\sqrt{\frac{\Delta p_e}{\Delta p_t}},$$

and

$$\frac{1}{K_t^2} = \frac{1}{K_e^2} + \frac{1}{K_d^2}.$$

In the efficiency relation

$$\eta_t = \frac{K_{1_t} K_3}{K_2 - \frac{K_4}{\eta}\frac{V}{nd}}$$

K_{1_t} includes both the pressure drop across the engine and

the pressure drop across the ducts. The latter cannot be considered useful, so the efficiency values given in this paper should be corrected by the relation,

$$\eta_{t\,(true)} = \eta_t \frac{\Delta p_e}{\Delta p_t}$$

after the pressure drop across the wing ducts is determined for the design under consideration.

Another factor in the efficiency relation is neglected in this analysis also, the term η representing the propeller efficiency. This term is necessary to transform the thrust or drag element due to the blowers from thrust power into brake power. It is not possible in this analysis to assign values of propeller efficiency to make this correction, so η is neglected entirely. Neglecting the propeller efficiency results in pessimistic blower efficiencies for the thrust producing conditions and optimistic efficiencies for conditions of drag, as may be noted from figure 6.

In reference 1 the test results for the various cowlings are given for a range of flow restrictions or conductivities which represent different engine sizes. The engine conductivity, K_e, is defined as the ratio of the equivalent engine orifice to the projected area of the engine. It would be possible to continue the use of the conductivity expression in this analysis of blowers but it is believed that to do so would result in considerable confusion in interpreting the results, because there is no inherent relation between blower and engine diameters. The blower for a given airplane should be designed to produce the required pressure and volume, which dictates the blower diameter and blade width. The range of orifice areas used for these tests should be considered as restrictions which produce various combinations of pressure, volume, and efficiency rather than a range of engine sizes. The restrictions are designated, therefore, as orifices 18, 19, etc., which have no particular meanings.

If the conductivity, K_t, is desired for any reason it can be computed from the relation,

$$K_t = \frac{K_3 d^2}{A_c \sqrt{2K_{1t}}}$$

The equivalent engine and entrance orifice area, $A_{(e+d)}$, is $\frac{K_3 d^2}{\sqrt{2K_{1_t}}}$. $\frac{A_{(e+d)}}{d^2} = \frac{K_3}{\sqrt{2K_{1_t}}}$ is a nondimensional ratio or restriction constant corresponding to K_t and may be used as a basis for comparing characteristics of blowers having different design diameters.

The results of the tests presented in this paper are outlined as follows:

I. Spinner of blowers 2 and 3 (no blower blades).
   (a) No propeller, figure 7.
   (b) With 4412 propeller, figures 8 to 12.

II. Blower 2.
   (a) Without guide vanes in exit slot and without propeller, figures 13 to 17.
   (b) With guide vanes but no propeller, figures 18 to 22.
   (c) With guide vanes and 4412 propeller, figures 23 to 25.

III. Blower 3.
   (a) With guide vanes in exit slot, figures 26 to 30.

IV. Blower 4.
   Without guide vanes in exit slot, figures 31 to 35.

V. Comparisons and other results.
   (a) Effect of guide vanes, figure 36.
   (b) Comparison between blowers 2 and 3, figure 37.
   (c) Comparison between blowers 3 and 4, figures 38 and 39.
   (d) Effective V/nd at wing-duct entrances.

      1. Propeller 4412, figure 40.
      2. Propeller 4412, figure 41.
      3. Propeller 6101, figure 42.

   (e) Comparisons between experimental and computed blower-propeller combinations, figures 43 to 45.
   (f) Maximum pressures obtainable with blowers 3 and 4, figures 46 and 47.

DISCUSSION

The design of blowers for commercial uses is well established and the characteristics of standardized types may be found by referring to handbooks. The problem of designing blowers to fit into the lay-outs of radial engine cowlings for the purpose of cooling the engine and which would operate at reasonable efficiencies is one not hitherto solved. The test program, consequently, consisted of intermittent designing, building, and testing with the idea of improving the existing types and gathering sufficient data that efficient blowers could be designed for specific cases. Blower 2 is an improvement on blower 1. (The results of blower 1 are not given.) Blower 3 is a further improvement. The use of guide vanes in the exit slot was decided upon only after blower 2 had been tested, so they were added even though the cowling lines were impaired. Blower 4 was designed after blower 3 had been tested in an attempt to increase the efficiency and also to avoid the use of guide vanes.

These blowers were all tested in conjunction with the wing-duct cooling system partly as a means for increasing the pressure obtainable with that system, and partly to determine the basic characteristics of blowers which were built onto propeller spinners. If the blowers proved to be sufficiently powerful and efficient to provide the principal means for cooling engines then the air intake could be located in a number of places on the airplane. Likewise the engine could be located almost any place within the airplane as far as the cooling system was concerned.

Control.- The problem of controlling the quantity of cooling air for the different flight conditions was not seriously considered in the early stages of development of the centrifugal blowers. It was thought that some means of restricting the exit slot opening could be devised if this means of cooling showed sufficient promise of fulfilling the requirements imposed so no tests were made of any control device until blower 4 was designed. In this design a simple device for restricting the flow through the blower blades was tested. (See fig. 5.) The test results, figures 31 to 35, indicate the method to be effective but somewhat inefficient.

It is believed that the most efficient method for restricting the flow at high speeds is by means of squeezing

down the exit slot width for all types of cooling systems. The exhaust air is accelerated at that point and a pressure drop across the slot is produced according to the relation, $\Delta p = \frac{1}{2} \rho V^2$. The velocity created by the process is useful in producing thrust or reducing drag. There is very little energy lost through a well-formed exit slot, so the only sources of energy loss are at the blower element or in the stream behind the exit slot.

If the blower were designed to produce the necessary boost in pressure for adequate cooling on the ground, that boost pressure could be maintained constant throughout the flight range by controlling the exit slot; so as far as the blower was concerned, controlling the exit slot would not affect its efficiency. Also, if the exit slot width for ground cooling were such that the exhaust air would have the same velocity as the free stream at that point, then the exhaust velocity and the free-stream velocity would be nearly equal throughout the flight range, so the mixing losses would remain nearly zero. From the efficiency standpoint a cooling system of this type could possibly be ideal if the blower were used only to restore the energy lost in the system from cooling the engine and through the ducts.

Methods for restricting exit slots are well established and need no particular discussion here. It is important to maintain smooth surfaces through the passage, whether the mechanism is based on the flap principle or on the principle of moving one portion of the cowling in a fore and aft direction.

Effect of guide vanes in the exit slot.- In figure 36 are given the characteristics of blower 2 tested with and without guide vanes in the exit slot. It may be noted that the guide vanes have the effect of increasing the pressure, volume, power, thrust, and efficiency. It is not clear why the pressure should increase with the use of guide vanes because the vanes add another restriction to the flow. This general tendency seems to prevail for nearly all the tests, however, including those made with blower 3. (Blower 3 test results with no guide vanes are not included in this report.) The increase in the thrust, however, is to be expected because without the guide vanes the air emerges from the exhaust slot at a helix angle of about 40° to the thrust axis and in a conical pattern. With the guide vanes the air flows back along the cowling surface at an angle of 10° or less to the thrust axis. The

guide vanes increased the drag of the nacelle 1.4 pounds at 100 miles per hour with no air flowing because of the poor contour formed by their presence. The net thrust for both conditions of tests was based on the drag of the nacelle with no guide vanes, so whatever drag the guide vanes added during the tests was automatically subtracted from the thrust. The efficiency of a blower equipped with guide vanes properly faired into the cowling lines would, therefore, be expected to be somewhat higher than indicated by these tests.

Comparison between blowers 2 and 3.- Some pressure-distribution measurements along the stationary surface of blower 2 case indicated the velocity of the air in the blower throat was relatively high. The entrance opening to the blower proper is probably too small for the best efficiency. Also the path of the air through the blower is relatively long which means the frictional losses might be high.

Blower 3 was designed to correct these indicated defects. Figure 37 shows that blower 3 is superior to blower 2 in every respect, the peak efficiency being about 12 percent higher. It seems paradoxical that the pressure should be higher for blower 3 than for blower 2 even though the active blades are shorter. The most reasonable explanation of this is that the frictional losses are less for blower 3 than for blower 2.

Comparison between blowers 3 and 4.- Blower 4 was designed in an effort to increase the efficiencies obtained with blower 3 and to eliminate the use of guide vanes in the exit slot.

In figure 38 blowers 3 and 4 are compared. It is not possible to base the comparison on the same orifice size if the coefficients are computed on bases of different design diameters. The comparison is therefore made on the basis of the same $A_{(e+d)}/d^2$ which is a nondimensional ratio that has the effect of proportioning the engine-orifice size to that of the blower. It may be seen from figure 38 that blower 4 produces a higher pressure and absorbs less power than blower 3 of the same design diameter. Blower 4 produces less thrust because the exit slot is much wider. The efficiency of blower 4 is from 11 to 20 percent higher than that of blower 3, exceeding 70 percent at the higher V/nD values of the test. Tuft studies of the flow leaving the exit slot indicated that little could be

gained by the use of guide vanes in the exit slot of blower 4 because the exhaust angle was only about 15° and there was no indication of flow separation from the cowl surface.

In figure 39 blowers 3 and 4 are compared on the basis of the cowling diameter rather than on the design diameters. This comparison is made to show that for a certain limiting diameter of the spinner, blower 3 is more powerful than blower 4. In this comparison the added diameter due to the guide vanes of blower 3 is neglected.

Effect of propellers.- The propeller plays an important part in the characteristics of a cooling system if the entrances or exits of the cooling air are located within the slipstream. It is obviously not possible to test blowers and propellers together in all the combinations of propeller diameters, blade angles, blower diameters, and blower blade widths that are necessary to cover the field of design requirements. A method for correcting blower results for the effect of the slipstream is the most practical solution to the problem.

The results of all the blower tests are plotted against V/nd as the velocity parameter. If it is assumed that the propeller adds a velocity increment uniformly over the propeller-disk area the slipstream effect may be taken into account by determining the effective V/nd of operation for computing the blower characteristics. The slipstream velocity is not uniform but the effect of the slipstream at the entrance ducts is probably much greater than at the exit slot; so the resultant velocity at the entrances is used in this analysis for determining the effective V/nd.

In figure 40 the effective V/nD is given for propeller 4412. The propeller diameter is used in computing both values of V/nD. In order to apply the results to the blower tests the values must be translated into terms of blower diameter. (See fig. 41.) Figure 42 gives effective values of V/nD for propeller 6101.

In figure 43 is shown experimental and computed pressure coefficients for several blower-propeller combinations. The experimental values are taken from figure 23. The computed values are taken from figures 18 and 41, combined by the process of plotting K_{1_t} corresponding to the effective V/nd against the true V/nd. The curves

indicate that the computed values exceed the measured values, probably due to the slipstream velocity being not as high at the exit slot as at the entrance ducts. The curves indicate the experimental pressure curves lie about three-fourths the distance between the blower-alone curves and the computed curves.

The power results, figure 44, are computed by first determining the power of the blower in the presence of the slipstream in the same manner as for the pressure, and then adding the power of the propeller alone. As both blower and propeller were tested separately with the spinner, it is necessary to subtract the power of the spinner alone (fig. 7) to avoid having this quantity added in twice.

In figure 45 the volume results are given. The method for computing is the same as that for the pressure results.

Drag of blower cowlings.- The drag of the blower cowlings were in general slightly higher than for cowling 39 described in reference 1, but this difference need not exist because any of the blowers could be built in the spinner of cowl 39, even though guide vanes are built in the exit slot. The drag coefficient of 0.05 obtained for cowling 39 is considered, therefore, applicable to the blower cowlings.

Limiting pressures.- The maximum pressure a centrifugal blower is capable of producing for zero flow depends upon the diameter, rotational speed, and air density. This upper limit can always be approached for any flow condition if the blades are made sufficiently wide (assuming that the throat area is not restricted). Blowers designed in this manner are neither economical as regards power absorption nor as regards size, but this upper limit is of some interest nevertheless because it defines the boundary beyond which a design is impossible.

Figure 46 is a chart showing the maximum pressures obtainable for blower 3, assuming different rotational speeds and diameters. This chart shows that for present-day engines having propeller rotational speeds of between 1,000 and 1,600 r.p.m. the diameters necessary to produce a pressure of 6 inches H_2O range from 2.4 to 3.8 feet. Most large radial engines have diameters of between 3.75 and 5 feet, so it appears that little difficulty should be

encountered in obtaining sufficient pressure even though the blade widths are limited to relatively small values.

The limiting pressure available for blower 4 depends upon the stalling of the blades in addition to the diameter, rotational speed, and air density. There is no indication of a stall occurring in the present tests so this element need not be considered here. The limiting pressures obtained with blower 4 (fig. 47) are less than with blower 3, so slightly larger design diameters are required to produce a given pressure. In view of the fact that the design diameter of blower 4 is limited to about 75 percent of the cowling diameter, the maximum pressures obtainable for any given engine are considerably less than for blower 3.

Design of blowers.- In reference 1 a method for designing the wing-duct type of cowling is discussed briefly. If a blower were to be used with this type of cowling as a means for boosting the pressure, the design of the blower only need be discussed here. The problem will be, therefore, confined to the blower element, the determination of the design diameter and blade width necessary to produce a specified pressure and volume.

The method recommended for designing the blower element consists of: (a) Determining the diameter of the blower element necessary to produce the desired pressure, assuming a certain restriction to the flow, or vice versa. The restriction is determined by referring to the test results; the selection is done on a basis of efficiency. (b) Adjusting the blade width to handle the volume of air.

In this method of design the actual engine orifice area is not considered under (a). It is assumed that the engine orifice area is directly proportional to that for the test in question; in other words, the ratio $A_{(e+d)}/d^2$ remains constant. This defines a geometrical similar setup. Actually, the engine orifice area will probably be different from that assumed by this method, so the blower blades are scaled in the width direction, as under (b), in direct proportion to the differences in the test orifice area and the actual orifice area.

The design process can best be illustrated by an example.

Given:

1,000 hp. engine.

1,250 r.p.m. propeller speed.

56-inch engine diameter.

Required:

6-inch H_2O boost pressure from blower.

18,000 cu. ft. per min. volume.

Solution:

(a) If blower 4 is selected a design diameter of 40 inches may be used.

Blade width = 3.45 inches.

$K_{1_t} = 2.72$.

Orifice 19 results may be used if it is essential that the pressure be obtained at zero V/nd. (See fig. 31.)

(b) From figure 33 the volume is computed as 121.2 cu. ft. per second or 7,270 cu. ft. per min. The blade width computed under (a) must be increased by the ratio 18,000/7,270 to produce the required pressure-volume results. 18,000/7,270 x 3.45 = 8.53 in. blade width.

(c) The power, corrected for the increase in blade width, is then 44.1 horsepower.

This example illustrates the process of applying the test results to a design problem in an elementary manner; the design of the blower element only is considered here. The duct design and the effect of the slipstream are other problems and are dealt with elsewhere.

It may be noted in the example that the design diameter of the blower is chosen to be the largest permissible, which determines the blade width necessary. The reason for

selecting the greatest possible diameter is because blower 4 is limited in the pressure it is capable of producing, so the largest possible diameter should be first assumed.

If blower 3 were selected the design process would be reversed, because pressure is no object in most cases.

Solution based on blower 3 results:

(a) From figure 30 it may be seen that the highest efficiency is obtained at low air speeds with orifice 19 but at high speeds there is little choice between orifices 20, 21, or 22. Orifice 21 is selected for the example. From figure 26, K_{1_t} is taken as 2.6. Solving for diameter necessary to produce 6 in. H_2O, d = 3.4 ft. The blade width at the tip is 1.31 in.

(b) From figure 28, K_3 is read as 0.156. Solving for volume, Q = 127.5 cu. ft. per sec., or 7,650 cu. ft. per min. The blade width computed under (a) must be increased by the ratio 18,000/7,650. Blade width = 3.08 in.

(c) From figure 27, K_2 is read as 1.5. The power, corrected for the increase in blade width, is then 62.8 horsepower.

(d) From figure 29, K_4 is read as 0.33.
Thrust = 108 lb.
It may be noted, incidentally, that the power seems high for the foregoing examples. This may be accounted for by the fact that the efficiency is relatively low at zero V/nd. Also the blowers are producing a considerable thrust. The thrust for blower 3 is equivalent to about 30 b.hp. if produced by a propeller.

It is important in designing blowers that the important dimension be scaled in proportion to those for the test models given in figures 3, 4, and 5 as far as possible. Of particular importance is the throat area which should not be reduced to the point of restricting the flow appreciably.

The one element in the design of blower 4 neglected in this paper is the blade angle. The blower was tested at only one angle for the present tests. It might be desirable to increase the blade angle for the purpose of increasing the pressure at high rates of flow, but a method for correcting the results for changes in blade angle is not included because of the lack of substantiating tests.

CONCLUSIONS

1. Blowers having diameters less than those of present-day radial engines and rotating at propeller speeds are capable of producing pressures in excess of those required for cooling.

2. The maximum over-all efficiency obtained with centrifugal blowers was about 60 percent, and over 70 percent for a radial blower built with airfoil blades.

3. The results indicate that blowers mounted on propeller spinners could be built sufficiently powerful and efficient to warrant their use as the only or chief means of forcing air through the cooling system, thereby providing engine cooling which would be independent of the speed of the airplane.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 17, 1939.

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1. Biermann, David, and Valentine, E. Floyd: Preliminary Model Tests of a Wing-Duct Cooling System for Radial Engines. N.A.C.A. confidential report, February 1939. Spec. Rep. #101

FIGURE LEGENDS

Figure 1.- Wing-duct-blower set-up in the tunnel.

Figure 2.- Outline of wing-duct set-up with blower 3.

Figure 3.- Blower 2.

Figure 4.- Blower 3.

Figure 5.- Blower 4.

Figure 6.- An example illustrating the effect of the propeller efficiency on the calculated value of the blower efficiency.

Figure 7.- Characteristics of the spinner part of blowers 2 and 3, orifice 22. (No blades, guide vanes, nor propeller.)

Figure 8.- Pressure coefficient. Spinner parts of blowers 2 and 3 tested with 4412 propeller. (No blower blades nor guide vanes.)

Figure 9.- Power coefficient. Spinner parts of blowers 2 and 3 tested with 4412 propeller. (No blower blades nor guide vanes.)

Figure 10.- Volume coefficient. Spinner parts of blowers 2 and 3 tested with 4412 propeller. (No blower blades nor guide vanes.)

Figure 11.- Pressure coefficient based on propeller diameter. Spinner parts of blowers 2 and 3 tested with propeller 4412 set 13° at 0.75 R.

Figure 12.- Pressure coefficient based on propeller diameter. Spinner parts of blowers 2 and 3 tested with propeller 4412. Orifice 21.

Figure 13.- Pressure coefficient. Blower 2 only. No guide vanes in exit slot.

Figure 14.- Power coefficient. Blower 2 only. No guide vanes in exit slot.

Figure 15.- Volume coefficient. Blower 2 only. No guide vanes in exit slot.

Figure 16.- Thrust coefficient. Blower 2 only. No guide vanes in exit slot.

Figure 17.- Efficiency. Blower 2 only. No guide vanes in exit slot.

Figure 18.- Pressure coefficient. Blower 2 only with guide vanes in exit slot.

Figure 19.- Power coefficient. Blower 2 only with guide vanes in exit slot.

Figure 20.- Volume coefficient. Blower 2 only with guide vanes in exit slot.

Figure 21.- Thrust coefficient. Blower 2 only with guide vanes in exit slot.

Figure 22.- Efficiency. Blower 2 only with guide vanes in exit slot.

Figure 23.- Pressure coefficient. Blower 2 tested with 4412 propeller and with guide vanes in exit slot.

Figure 24.- Power coefficient. Blower 2 tested with 4412 propeller and with guide vanes in exit slot.

Figure 25.- Volume coefficient. Blower 2 tested with 4412 propeller and with guide vanes in exit slot.

Figure 26.- Pressure coefficient. Blower 3 only with guide vanes in exit slot.

Figure 27.- Power coefficient. Blower 3 only with guide vanes in exit slot.

Figure 28.- Volume coefficient. Blower 3 only with guide vanes in exit slot.

Figure 29.- Thrust coefficient. Blower 3 only with guide vanes in exit slot.

Figure 30.- Efficiency. Blower 3 only with guide vanes in exit slot.

Figure 31.- Pressure coefficient. Blower 4 only. No guide vanes in exit slot.

Figure 32.- Power coefficient. Blower 4 only. No guide vanes in exit slot.

Figure 33.- Volume coefficient. Blower 4 only. No guide vanes in exit slot.

Figure 34.- Thrust coefficient. Blower 4 only. No guide vanes in exit slot.

Figure 35.- Efficiency. Blower 4 only. No guide vanes in exit slot.

Figure 36.- Effect of guide vanes in exit slot of blower 2. No propeller. Orifice 21.

Figure 37.- Comparison between blowers 2 and 3. Guide vanes in exit slot. No propeller. Orifice 21.

Figure 38.- Comparison between blowers 3 and 4. No propeller. $\frac{A(e+d)}{d^2} = 0.069$. Guide vanes in exit slot of blower 3 only.

Figure 39.- Comparison between blowers 3 and 4. All coefficients based on the cowling diameter of 20 inches. Guide vanes in exit slot of blower 3. No propeller. Orifice 21.

Figure 40.- Effective V/nD at the wing-duct entrances with propeller 4412.

Figure 41.- Effective V/nd at the wing-duct entrances based on the design diameter of blowers 2 and 3. Propeller 4412.

Figure 42.- Effective V/nD at the wing-duct entrances with 3-blade 6101 propeller.

Figure 43.- Comparison between experimental and computed pressure coefficients of blower-propeller combinations. Blower 2 with guide vanes in exit slot. Propeller 4412.

Figure 44.- Comparison between experimental and computed power coefficients of blower-propeller combinations. Blower 2 with guide vanes in exit slot. Propeller 4412.

Figure 45.- Comparison between experimental and computed volume coefficients of blower-propeller combinations. Blower 2 with guide vanes in exit slot. Propeller 4412.

Figure 46.- Maximum pressures available for blower 3. Zero air flow and $\frac{V}{nd} \cdot K_{1_t} = 3.2$.

Figure 47.- Maximum pressures available for blower 4. Zero air flow and $\frac{V}{nd} \cdot K_{1_t} = 2.9$.

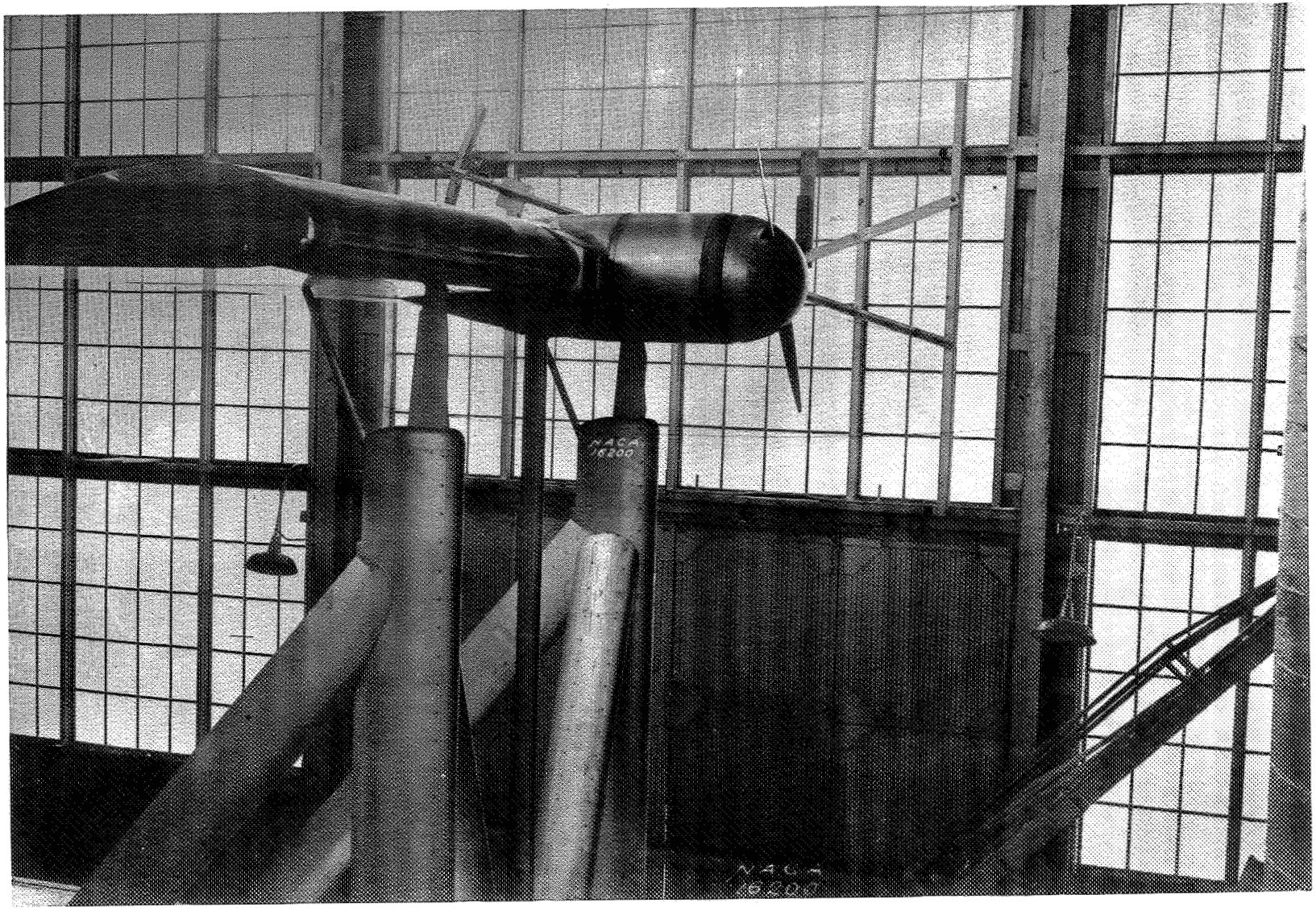


Figure 1.- Wing-duct-blower set-up in the tunnel.

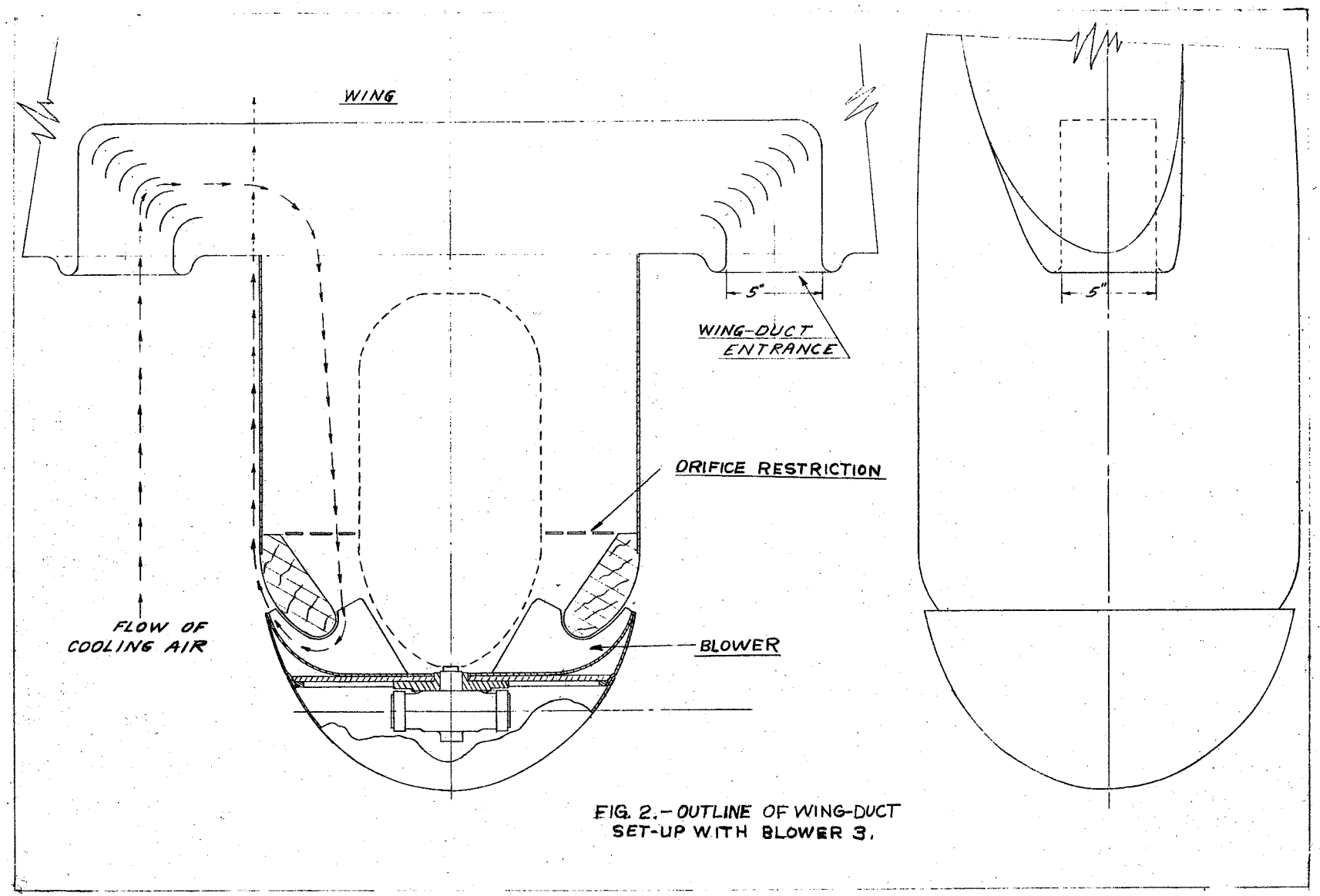


FIG. 2.- OUTLINE OF WING-DUCT SET-UP WITH BLOWER 3.

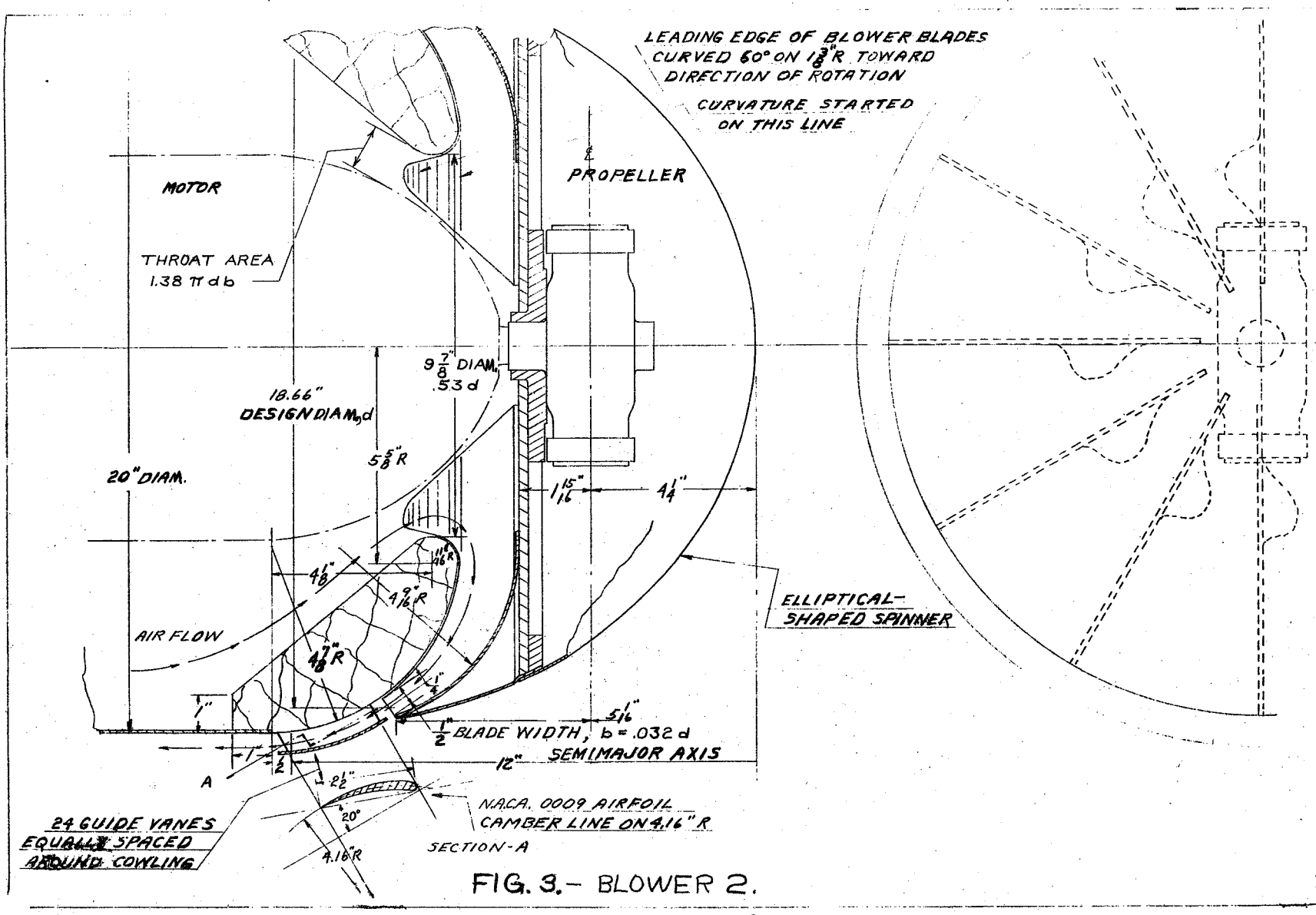


FIG. 3.- BLOWER 2.

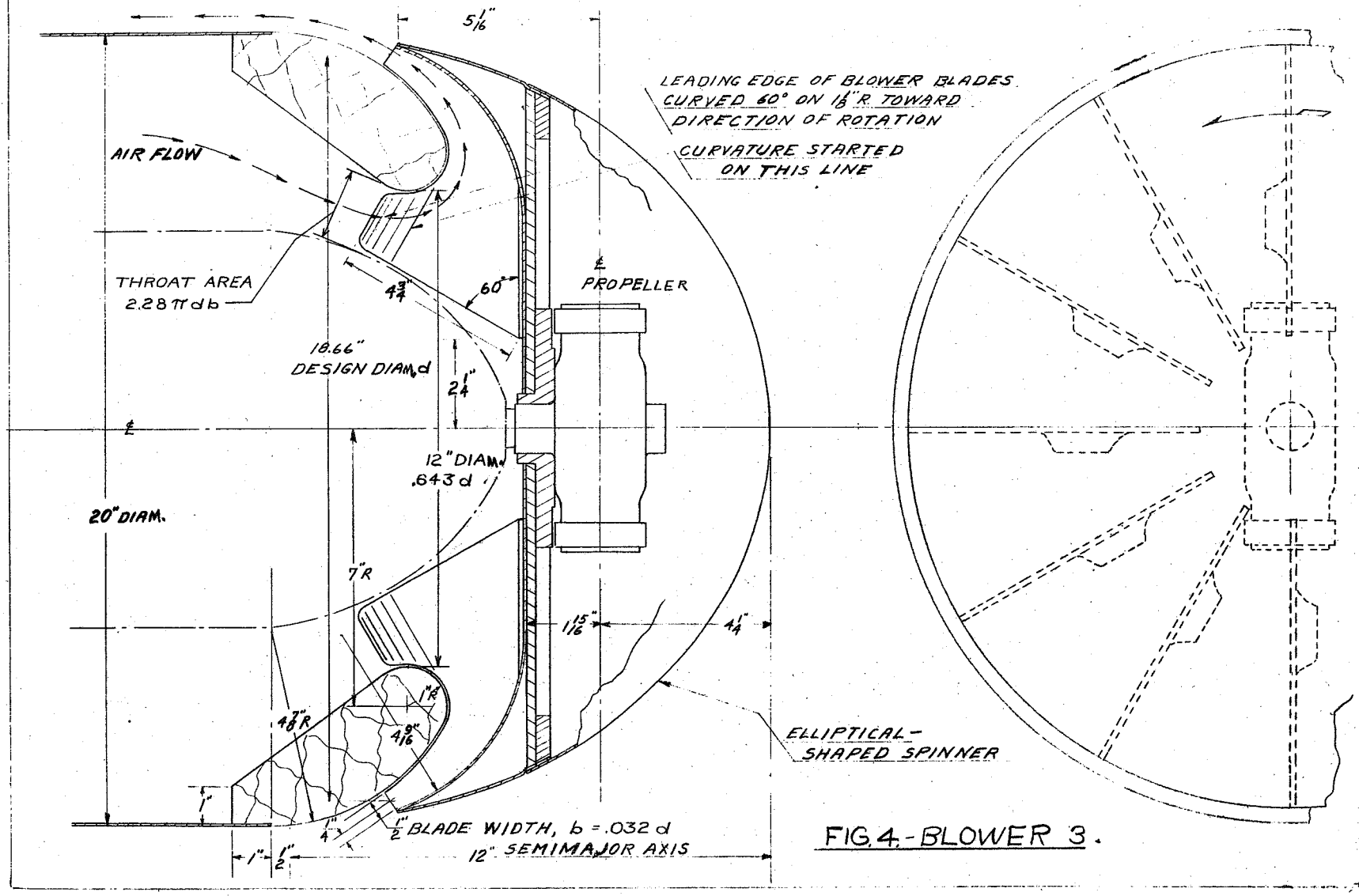


FIG. 4.- BLOWER 3.

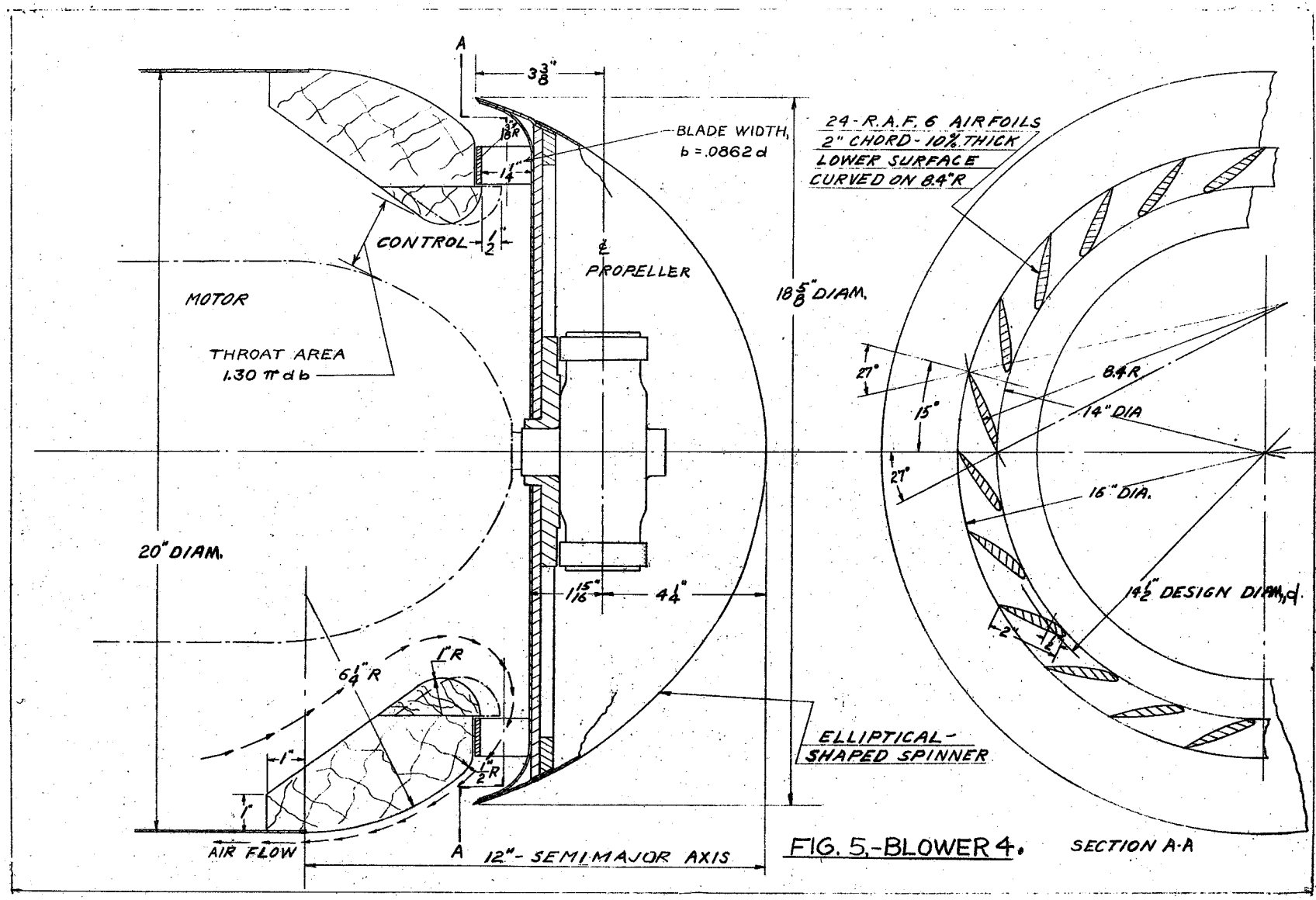
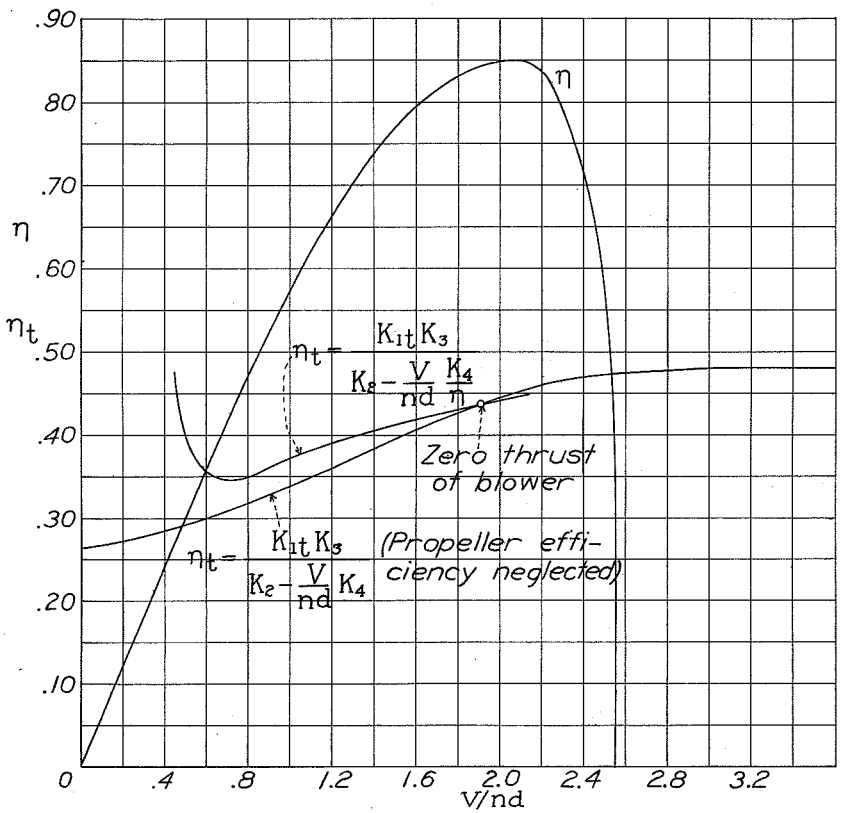


FIG. 5.-BLOWER 4.



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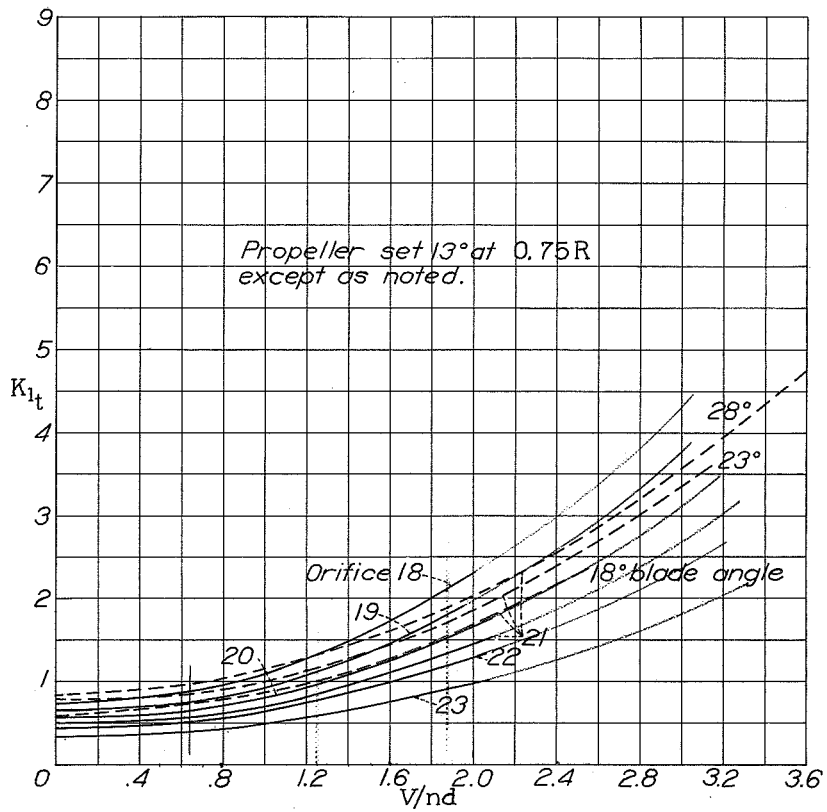

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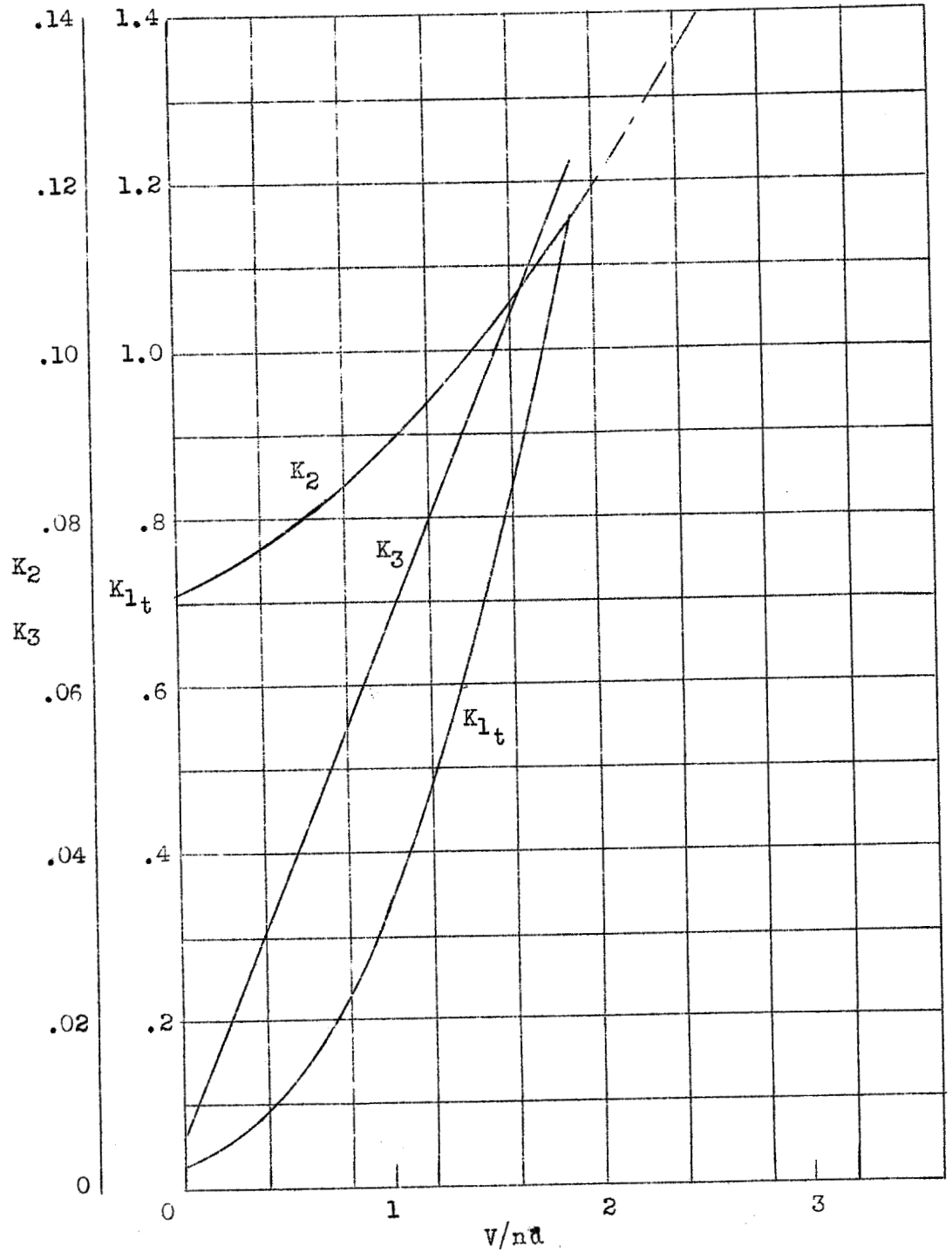

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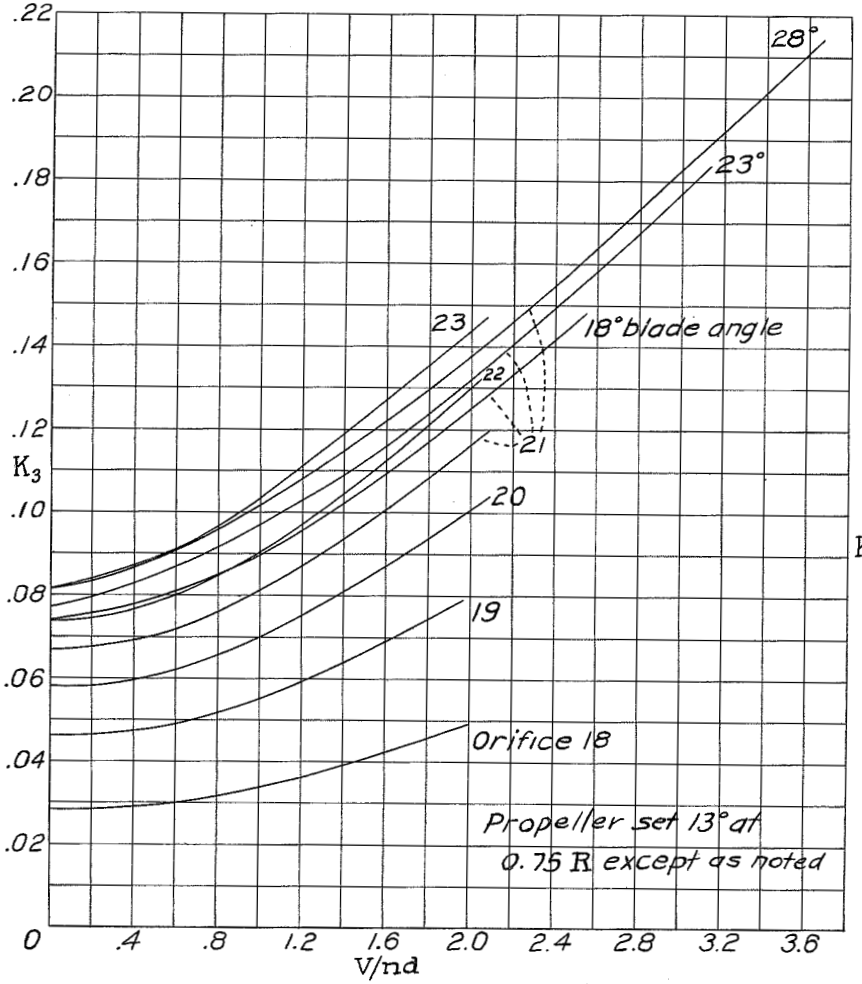

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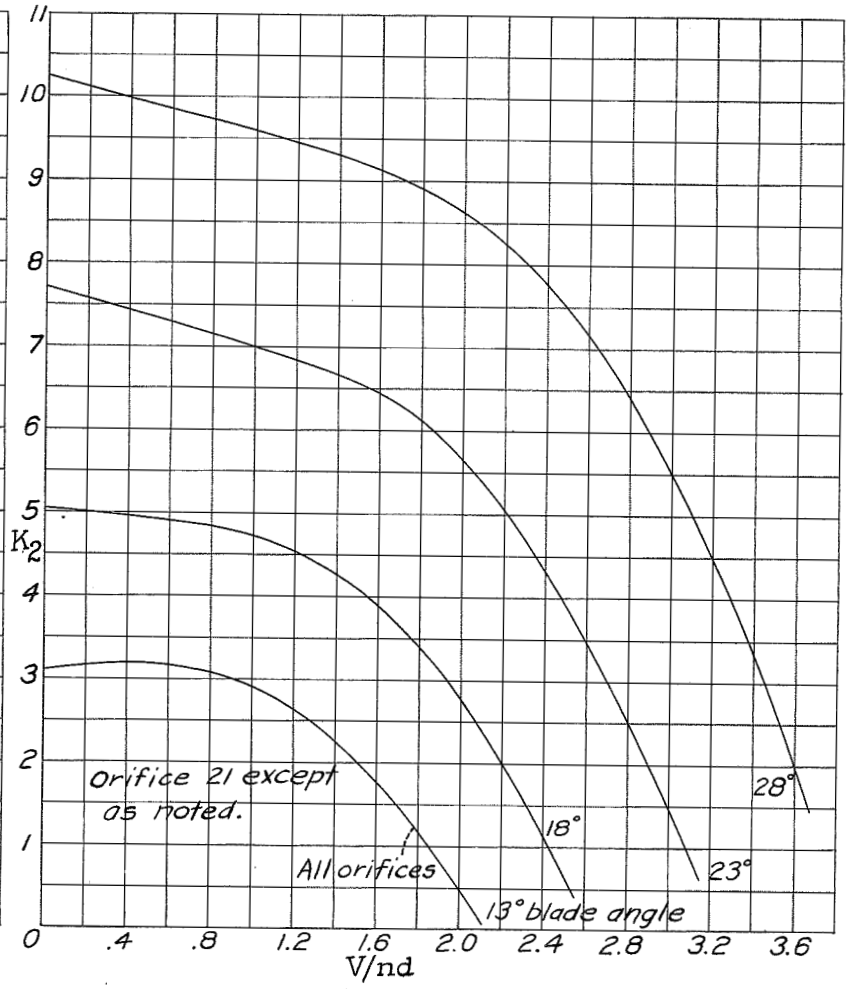

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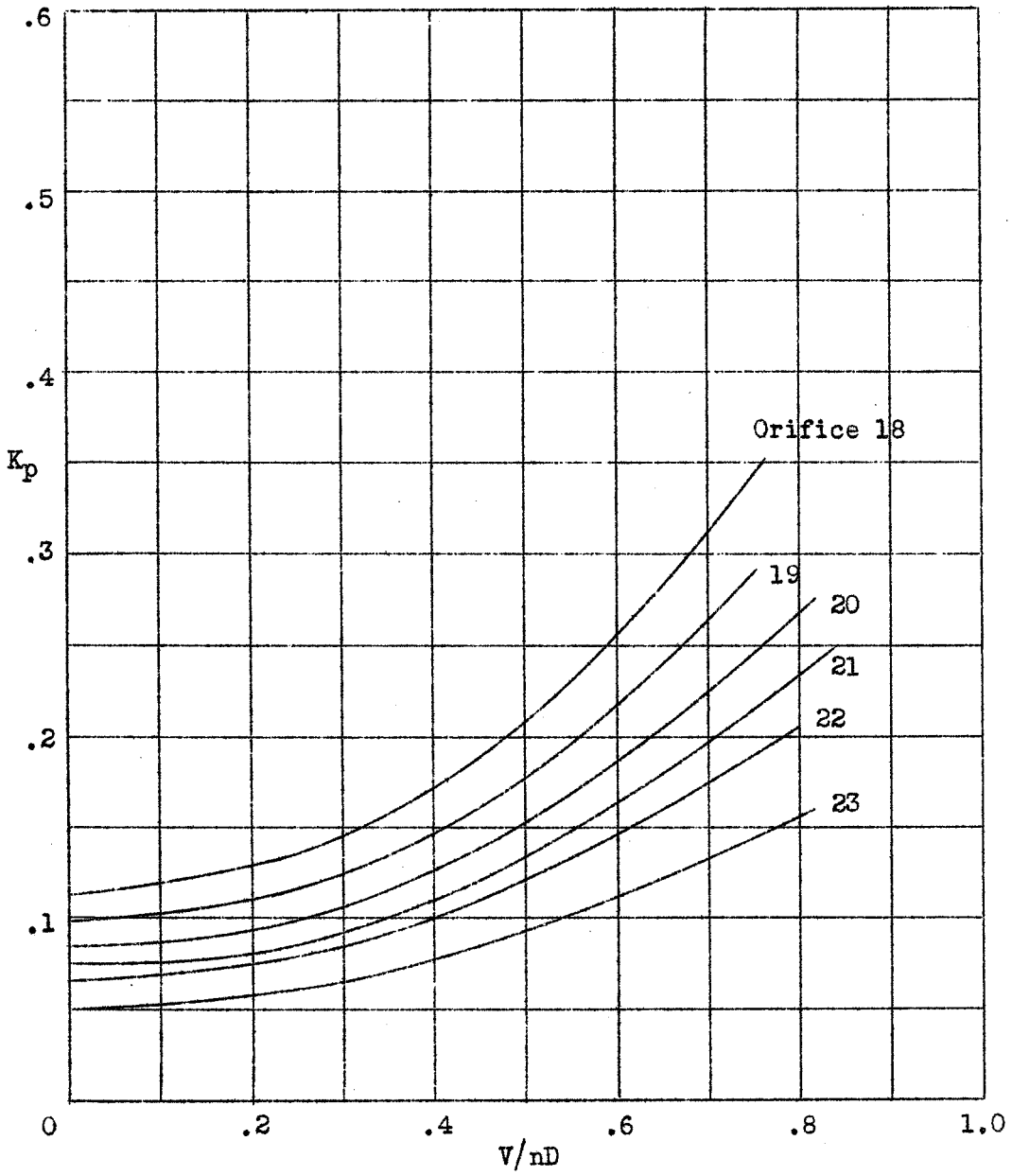

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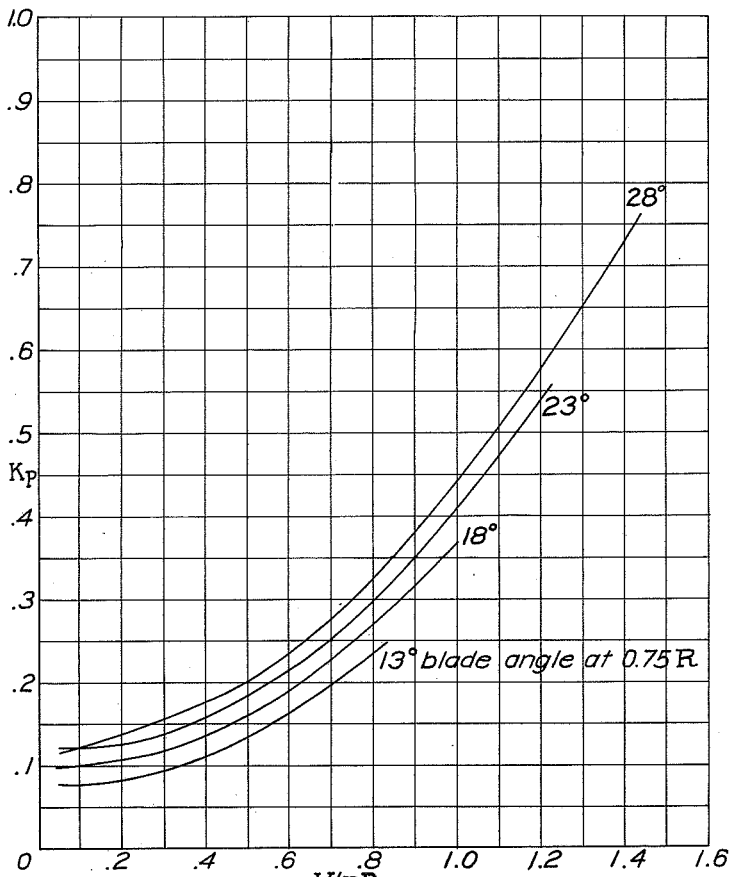

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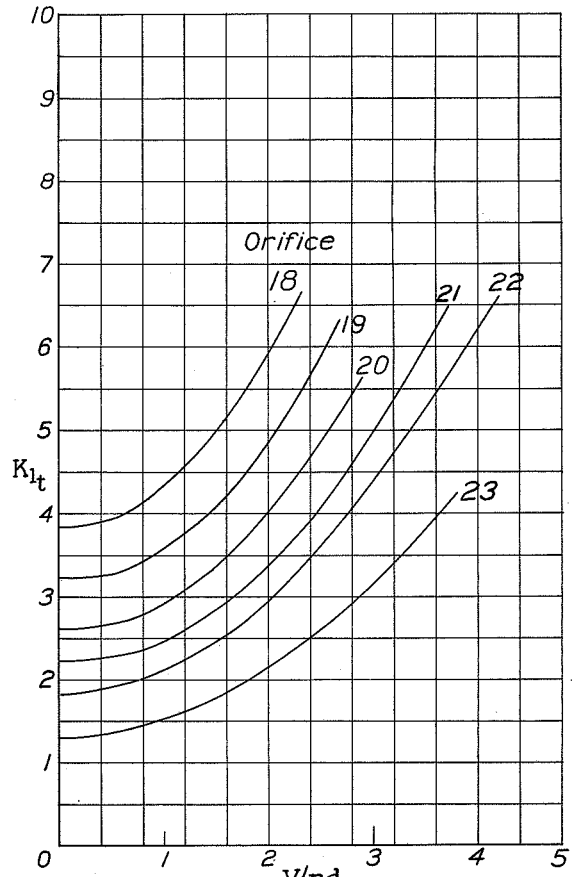

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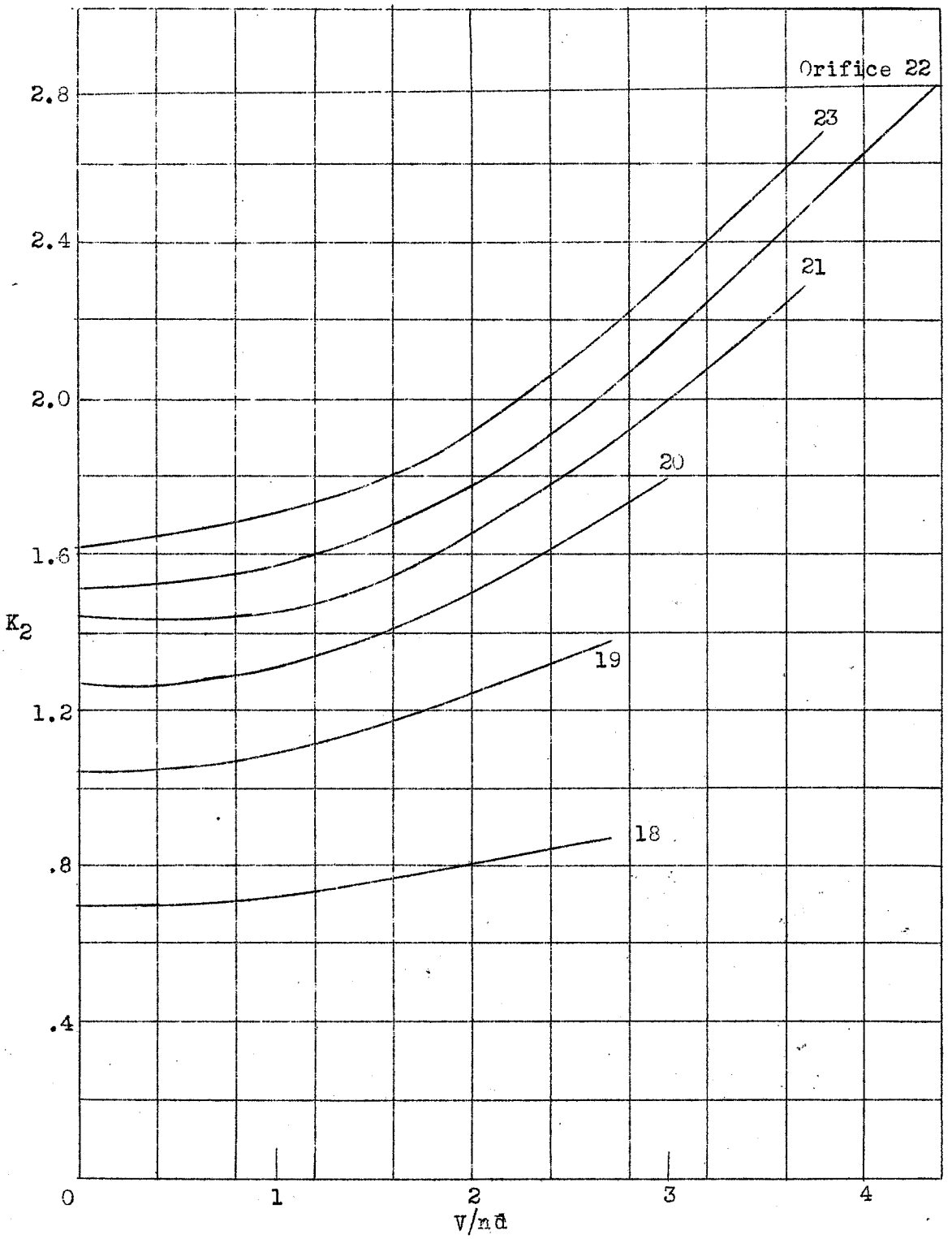

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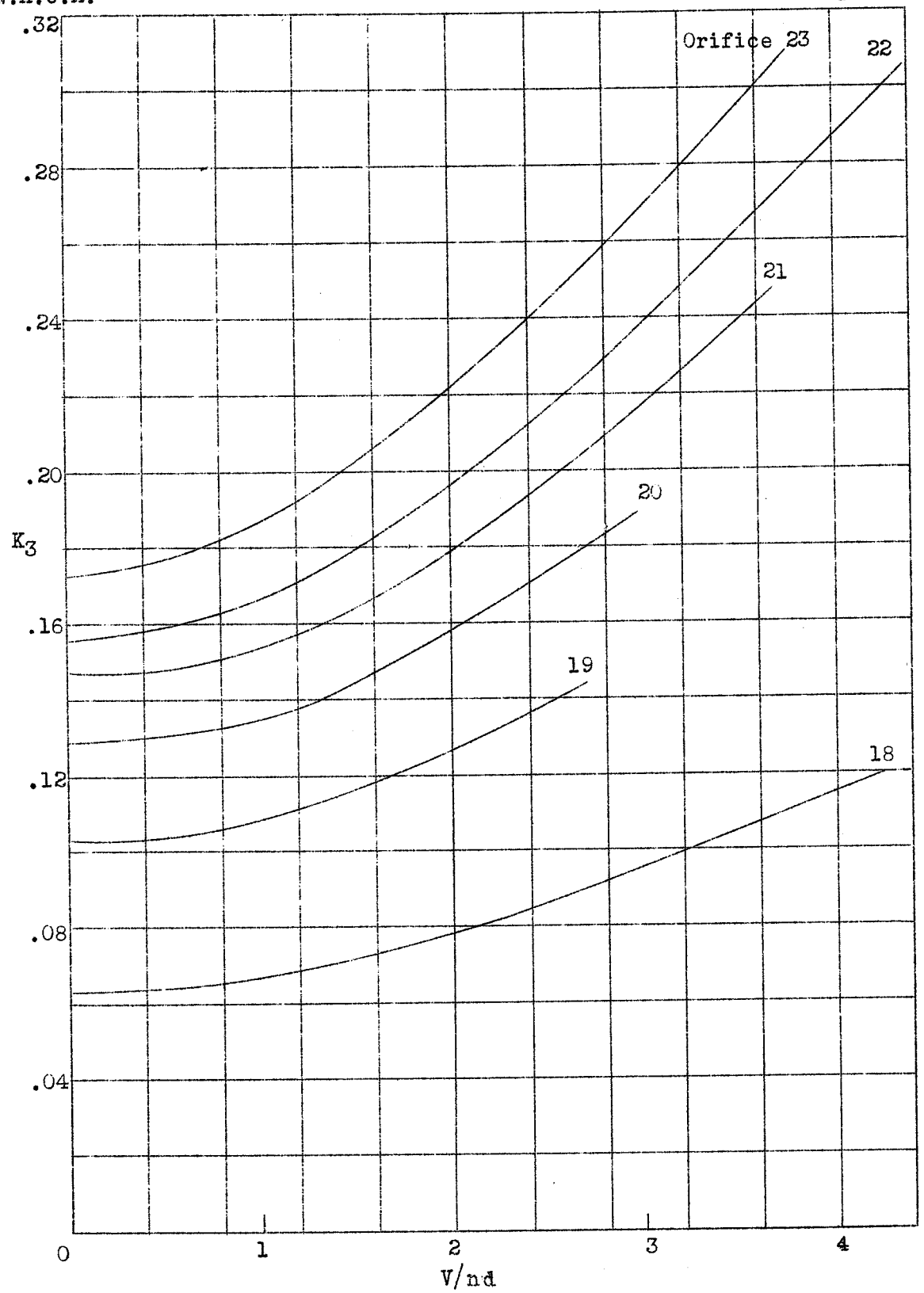

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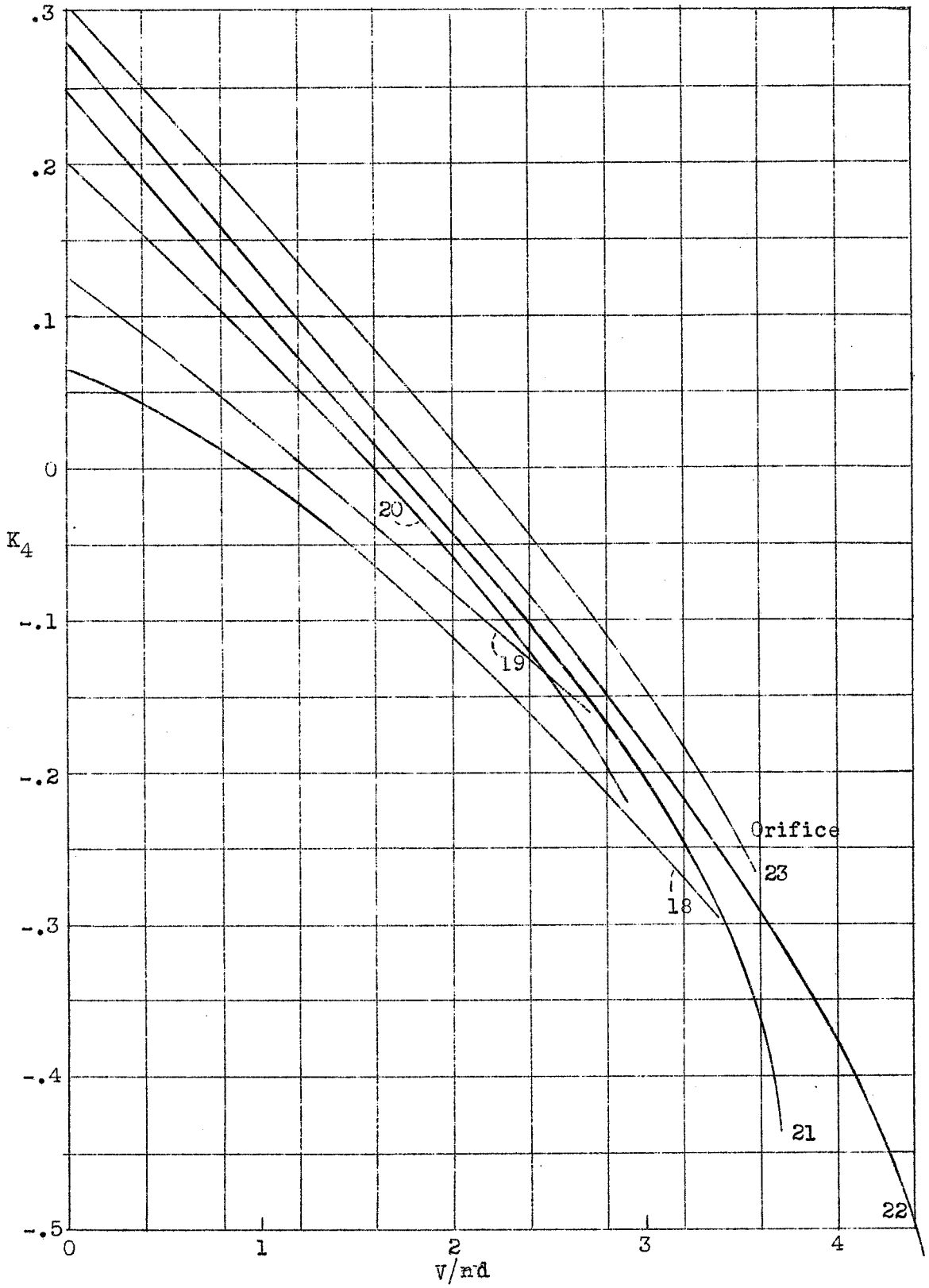

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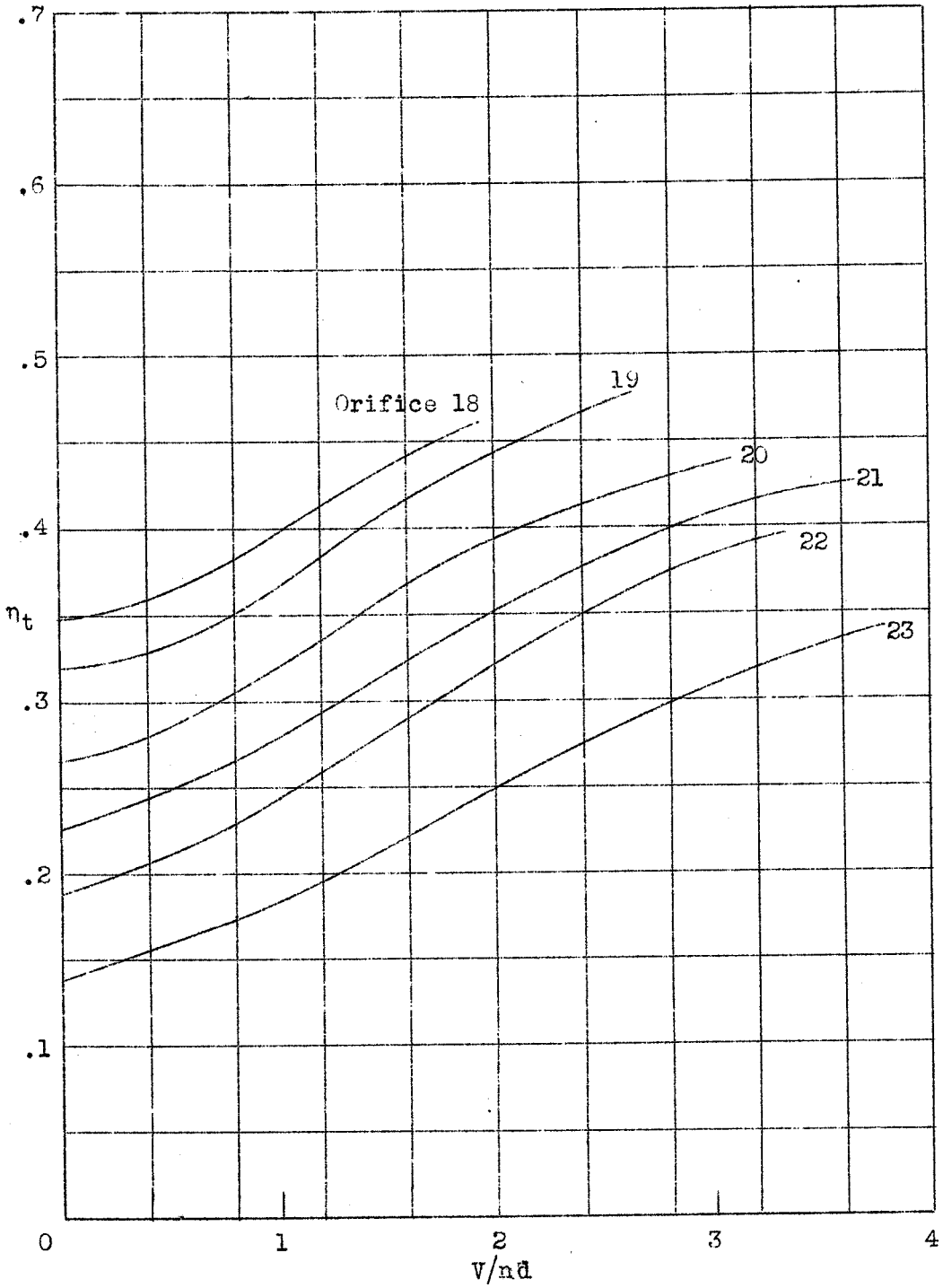

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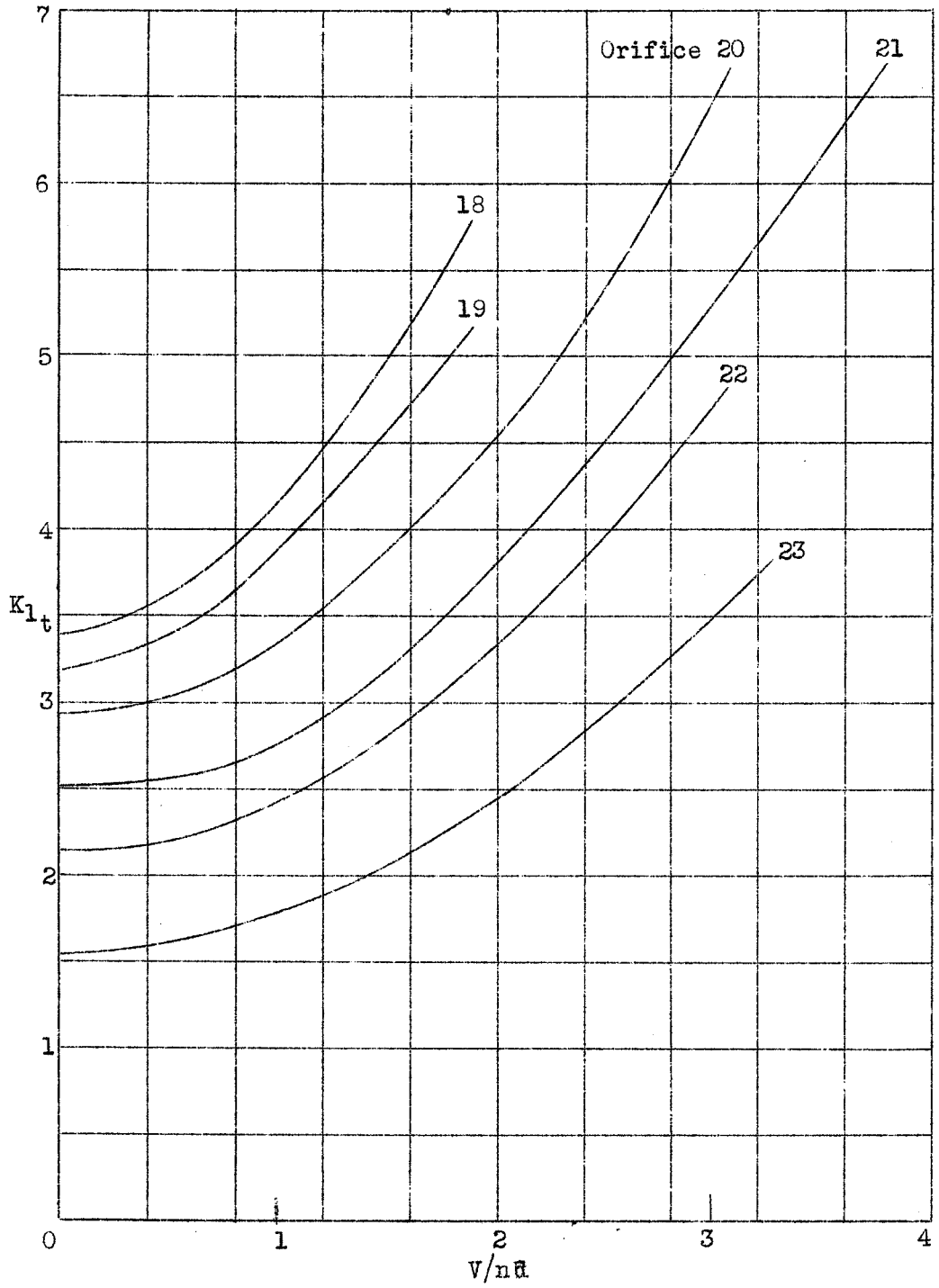

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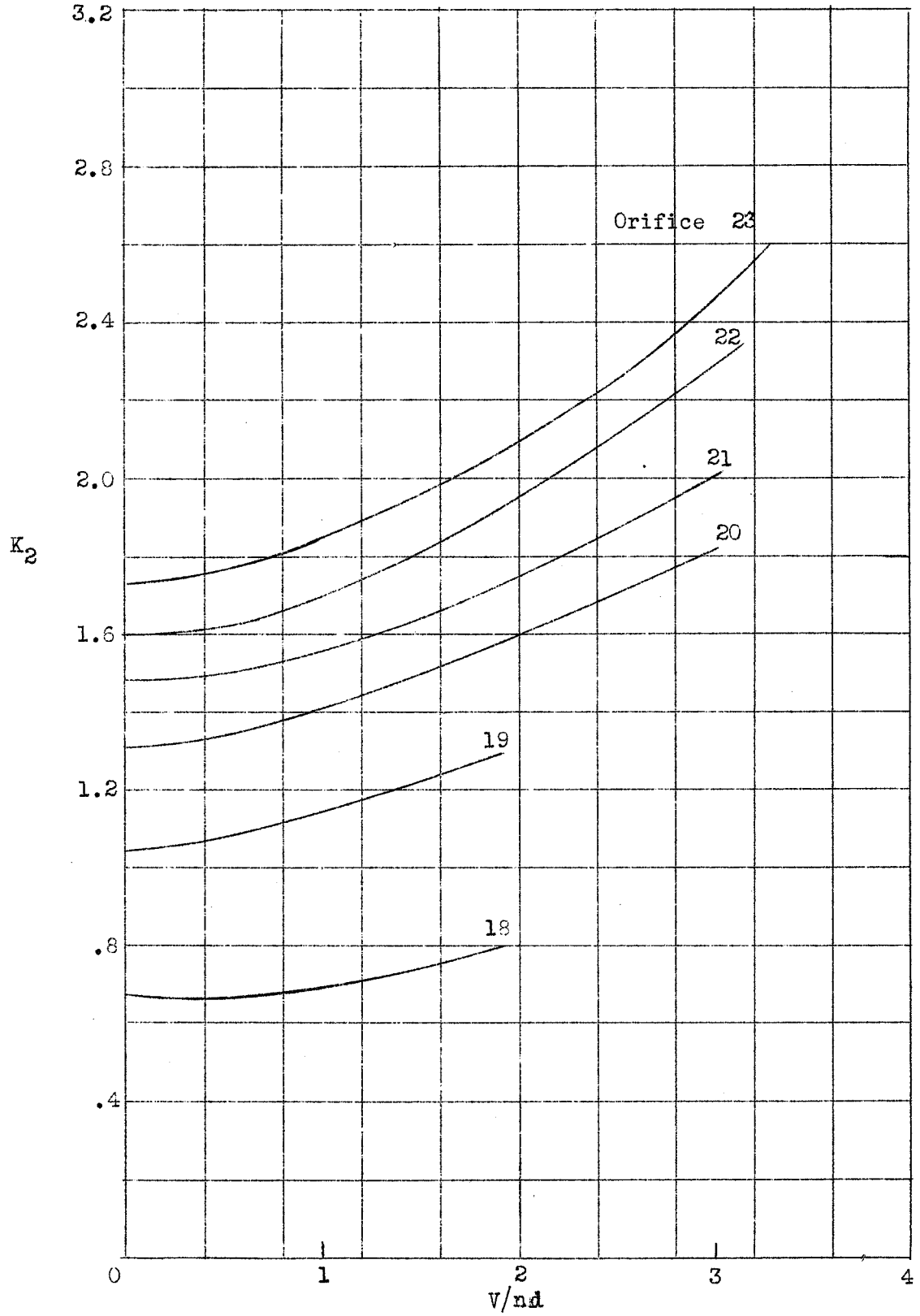

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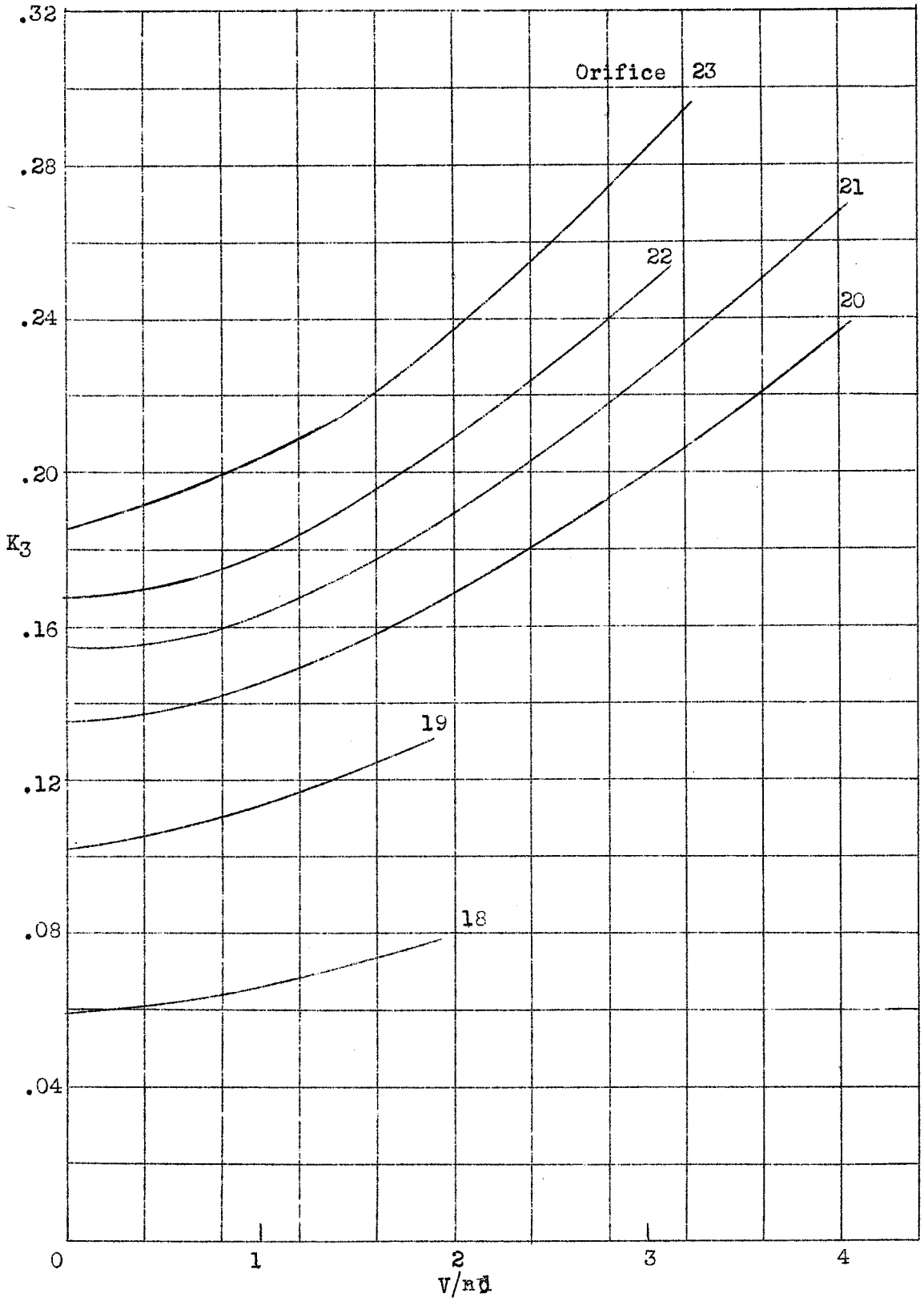

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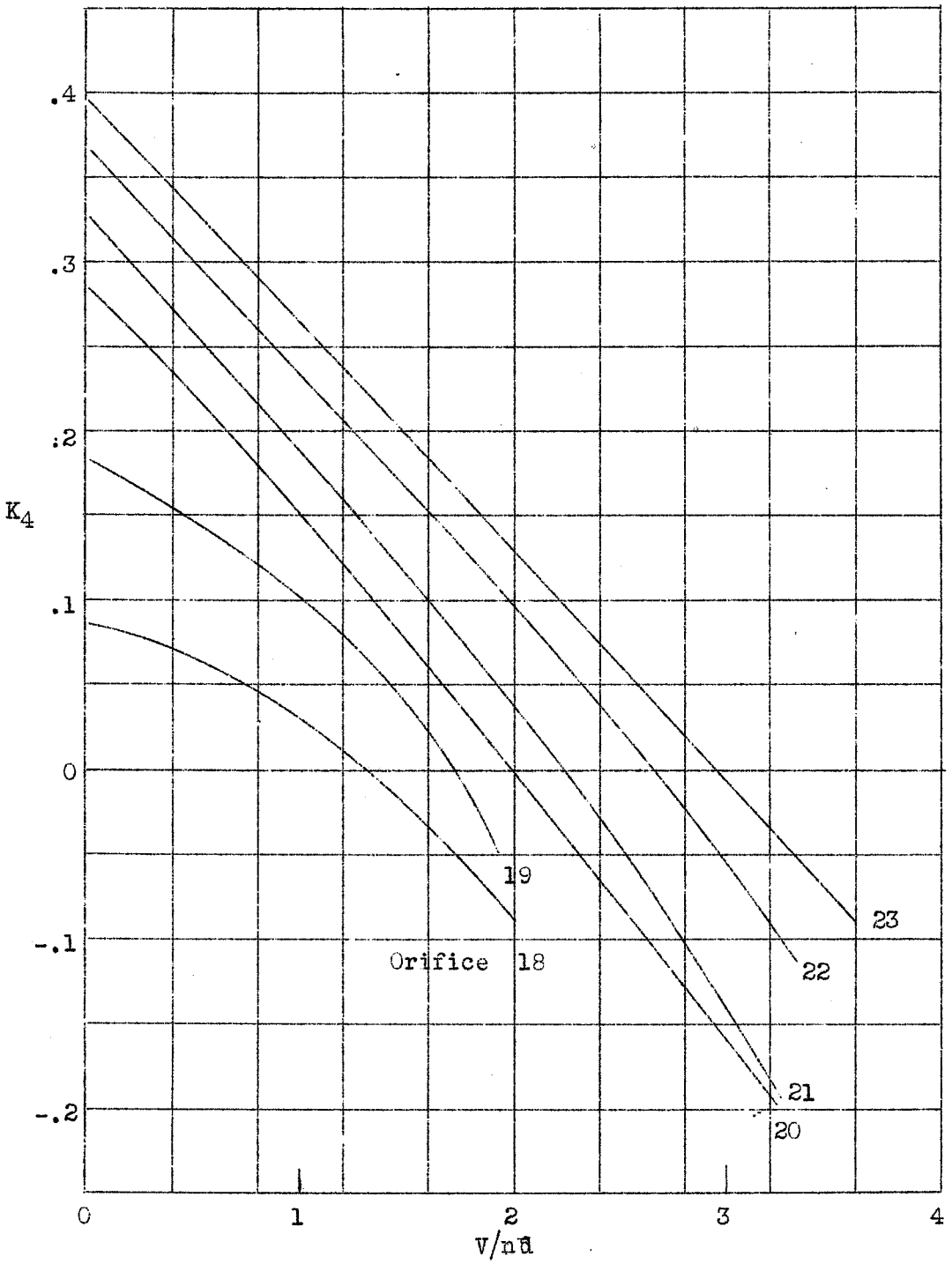

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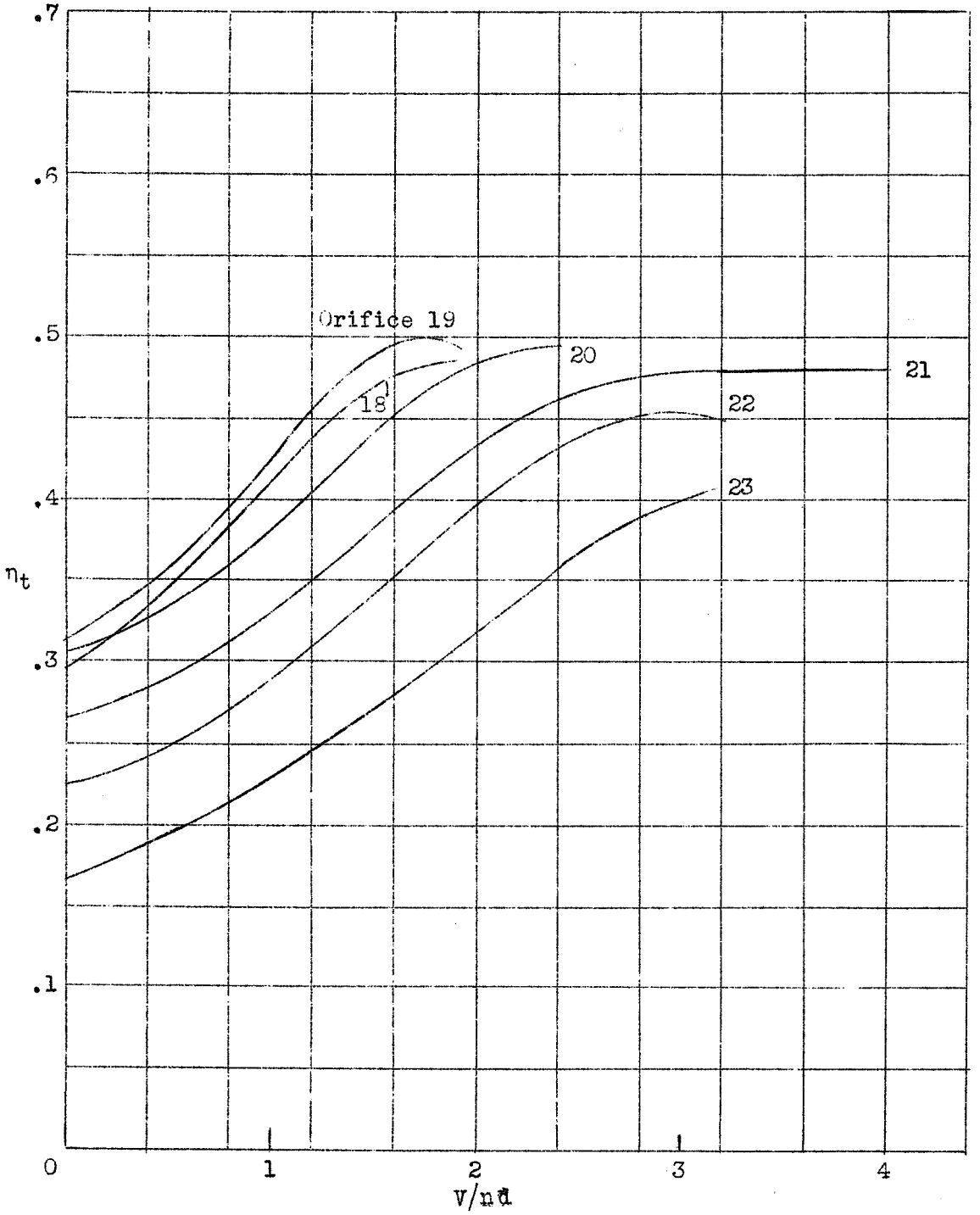

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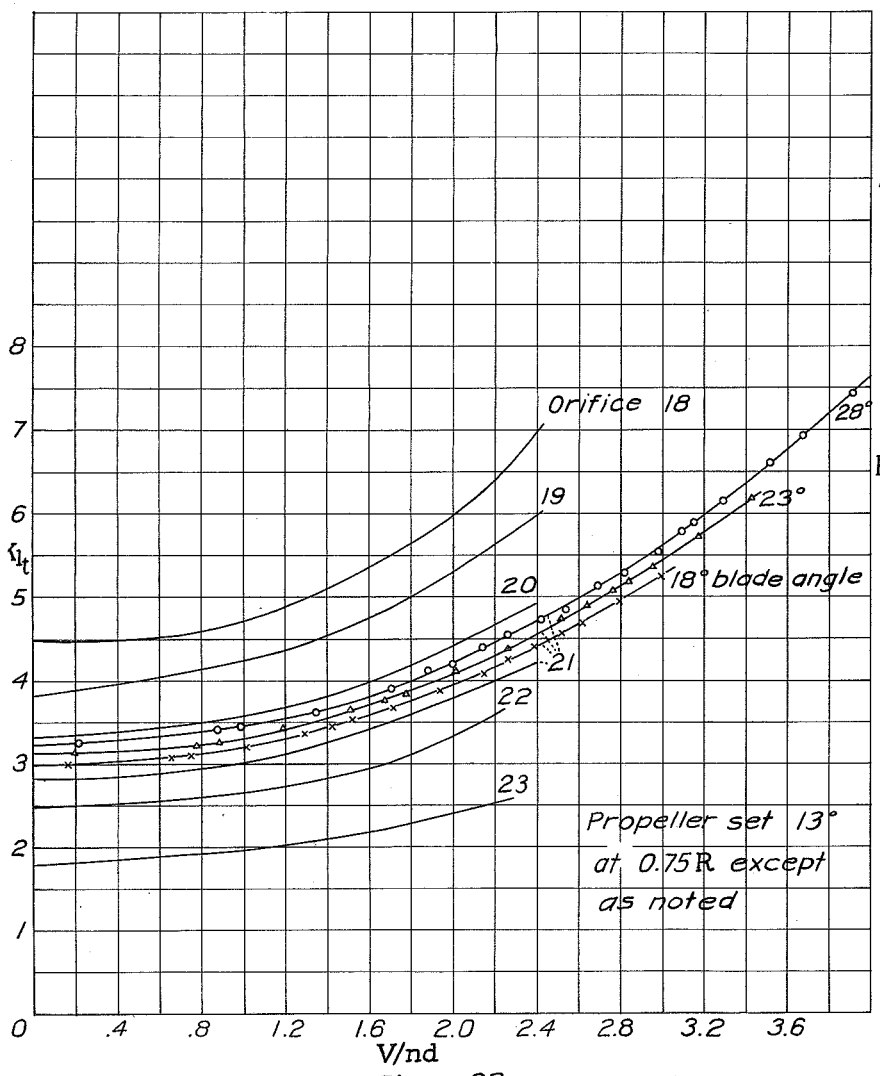

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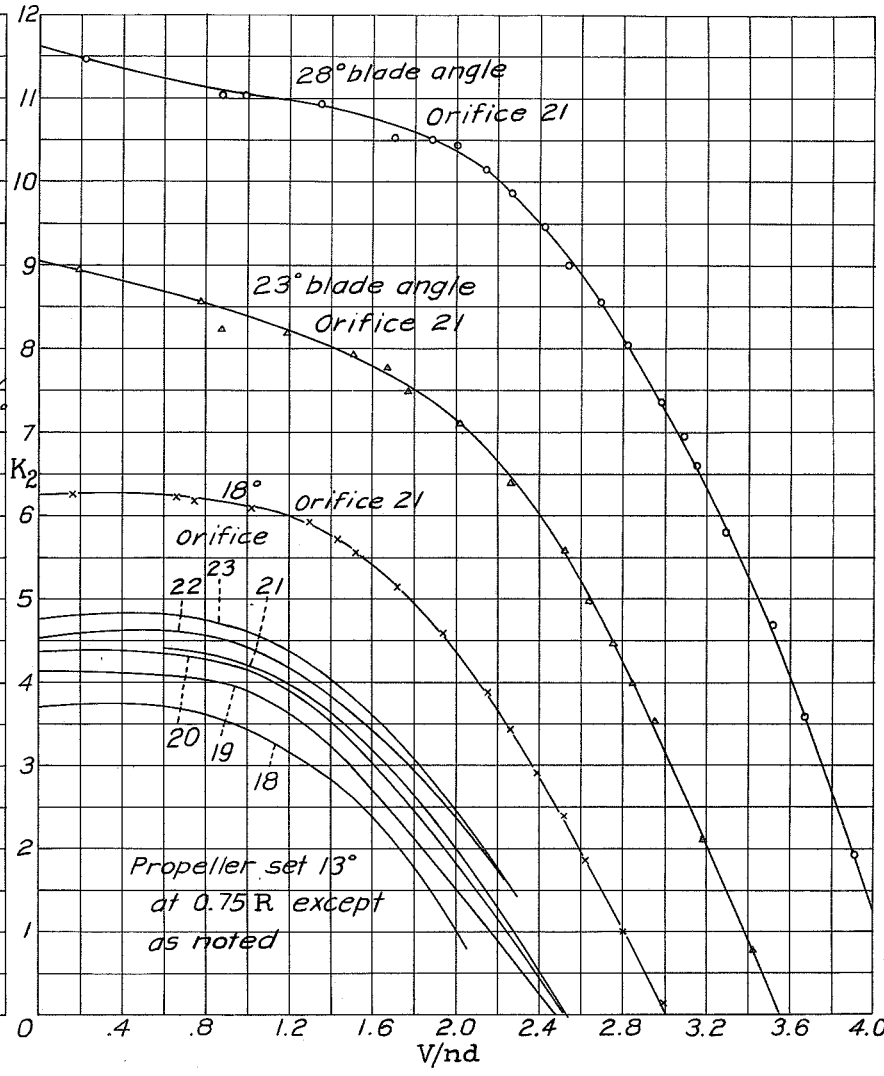

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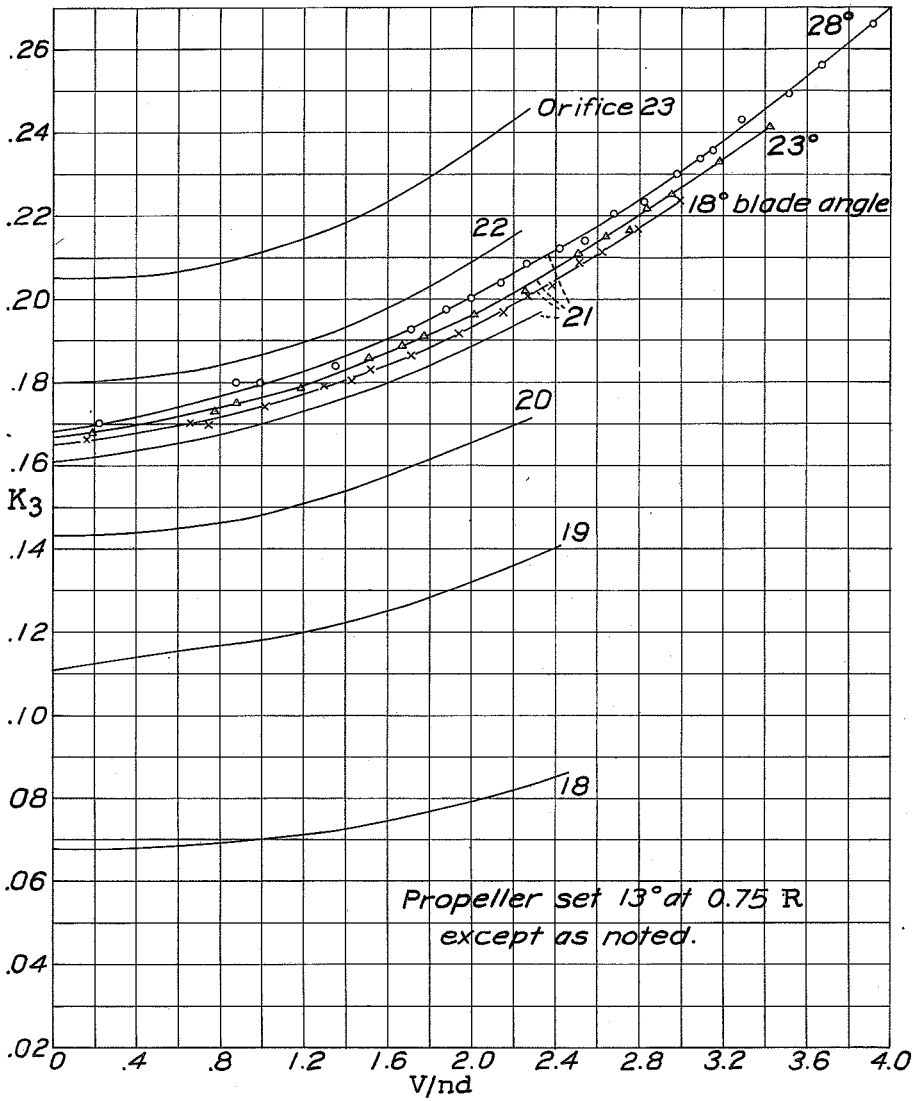

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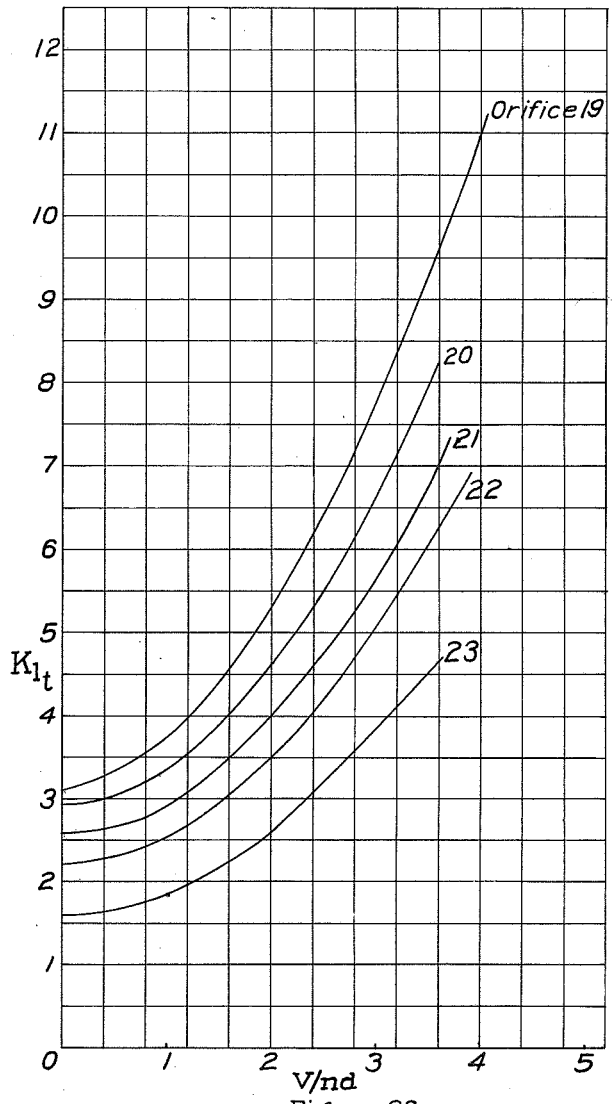

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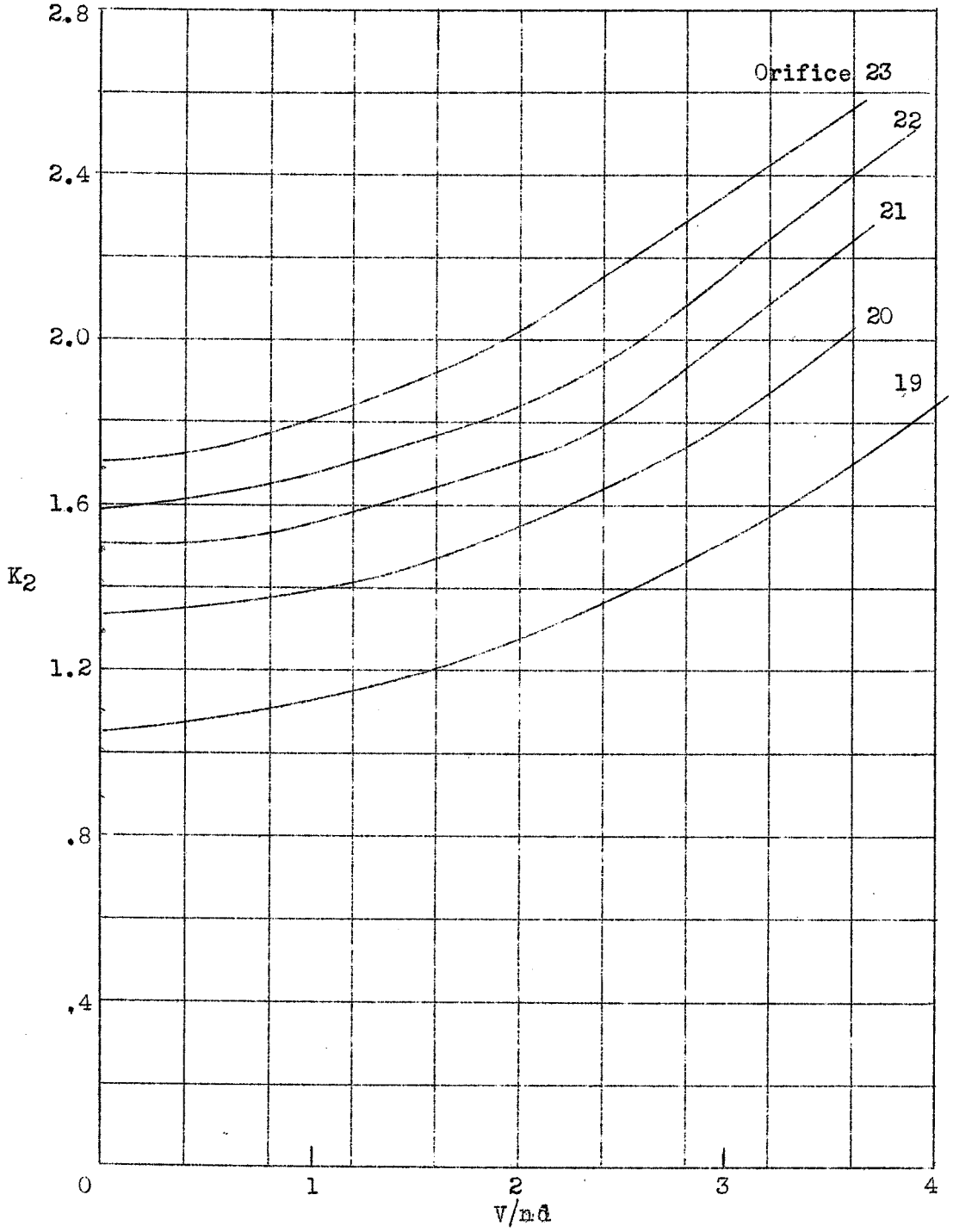

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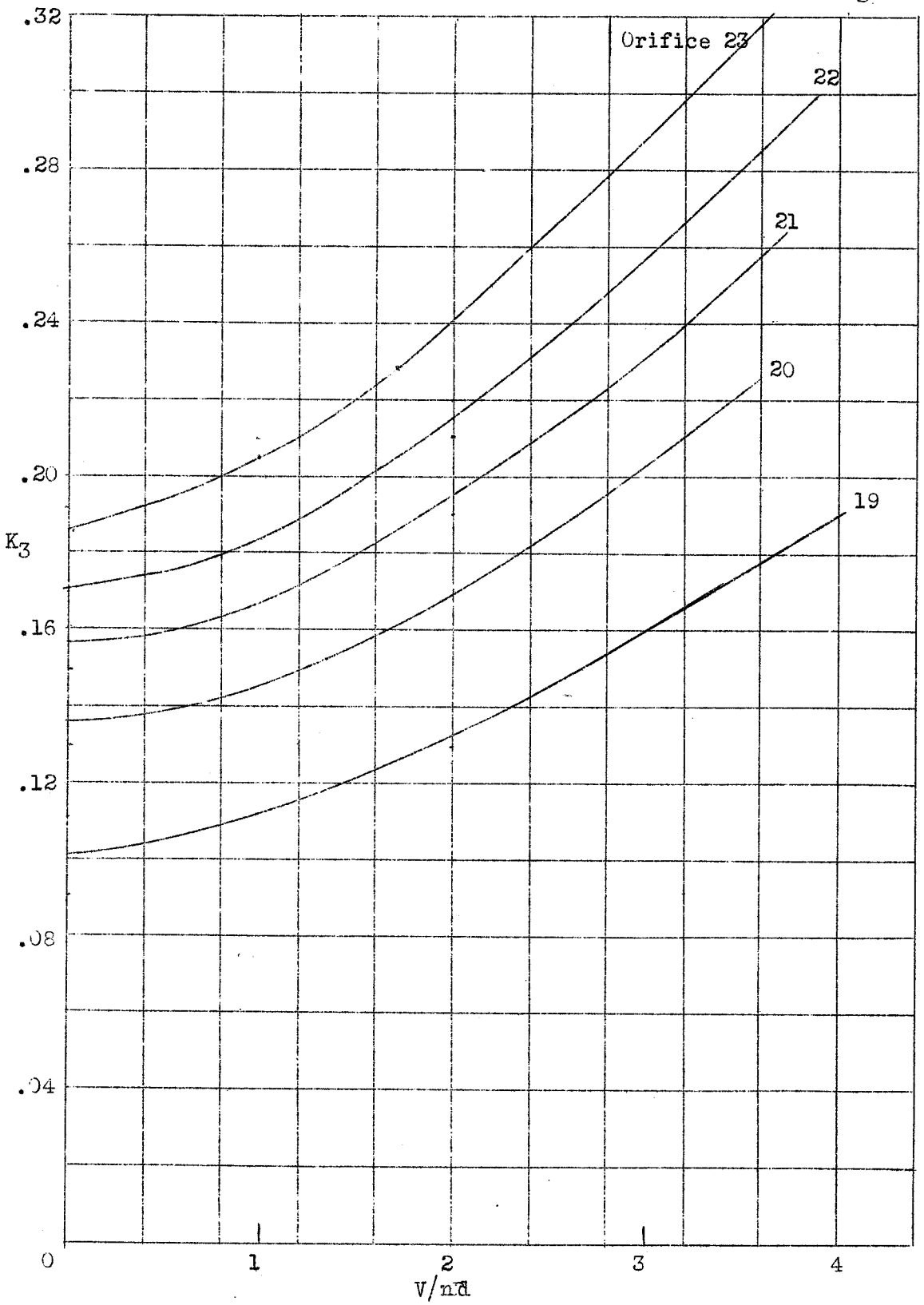

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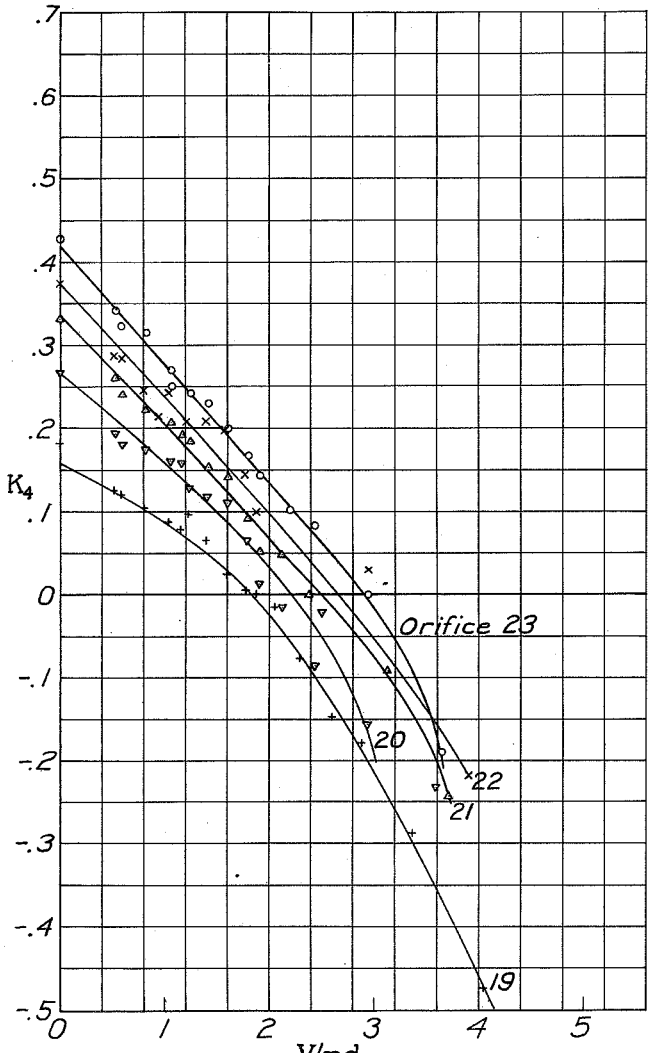

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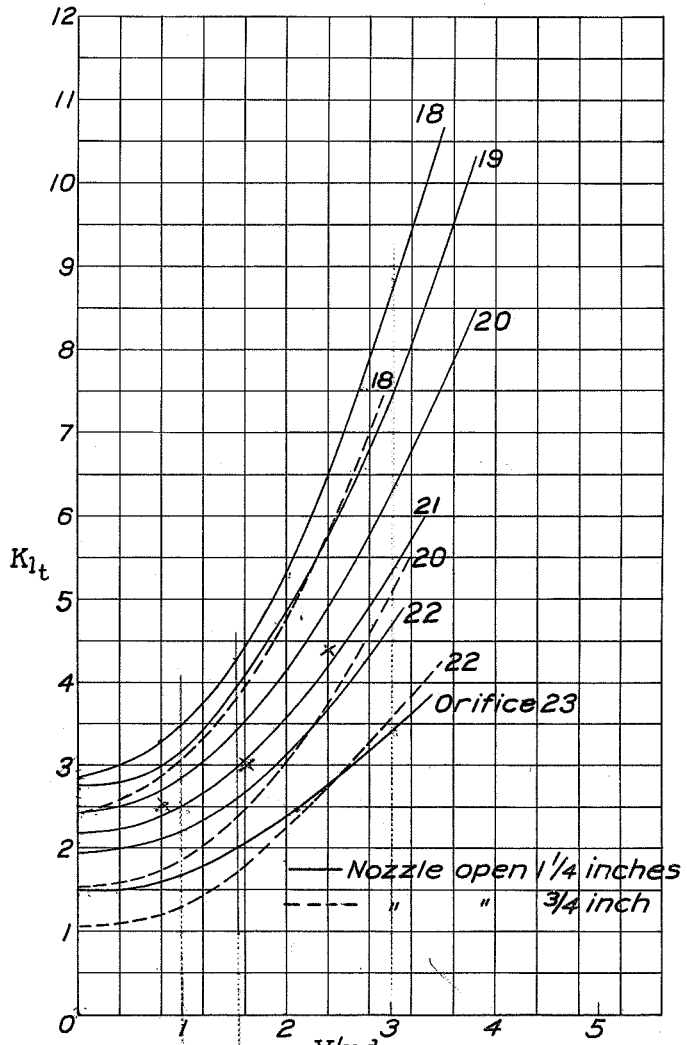

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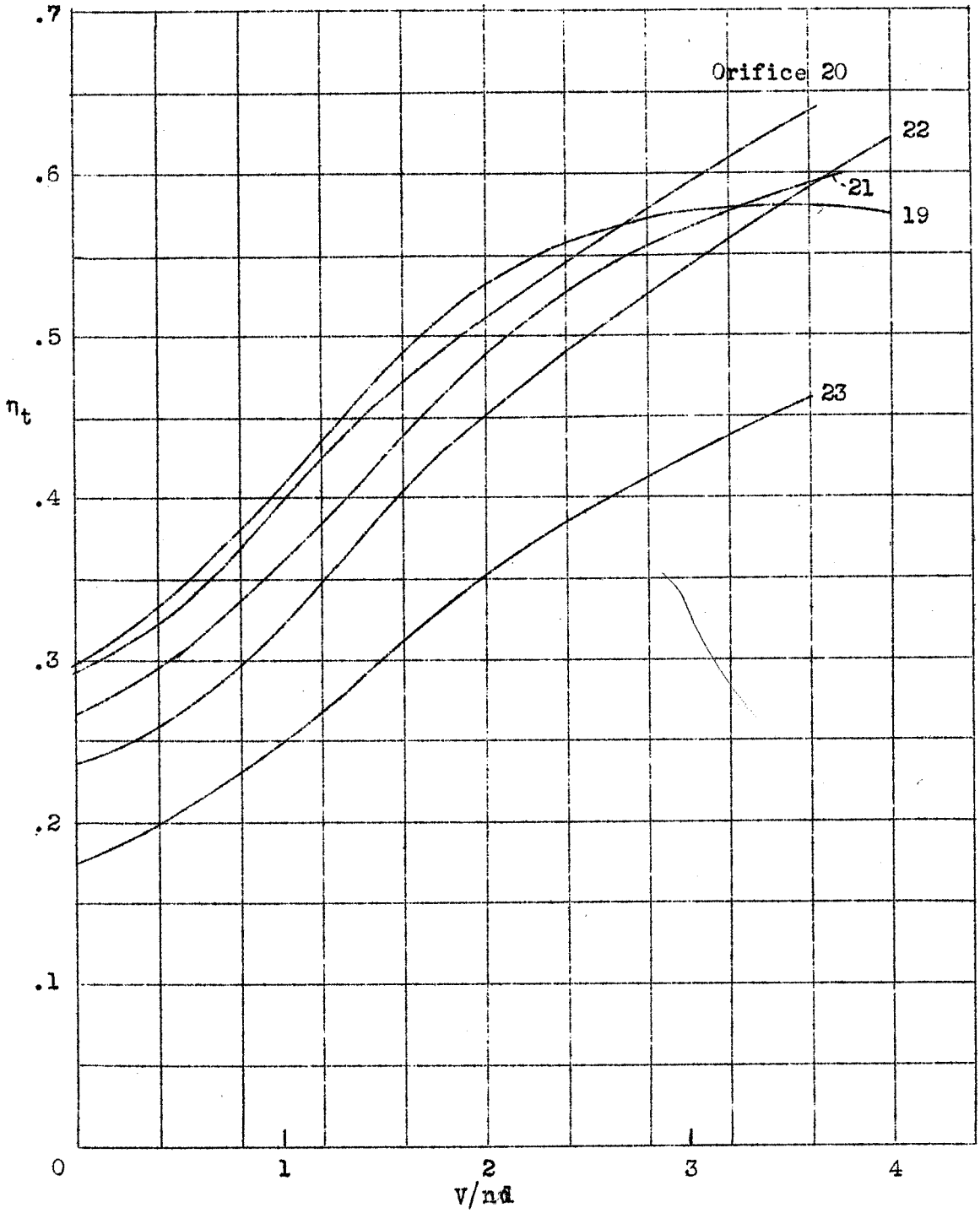

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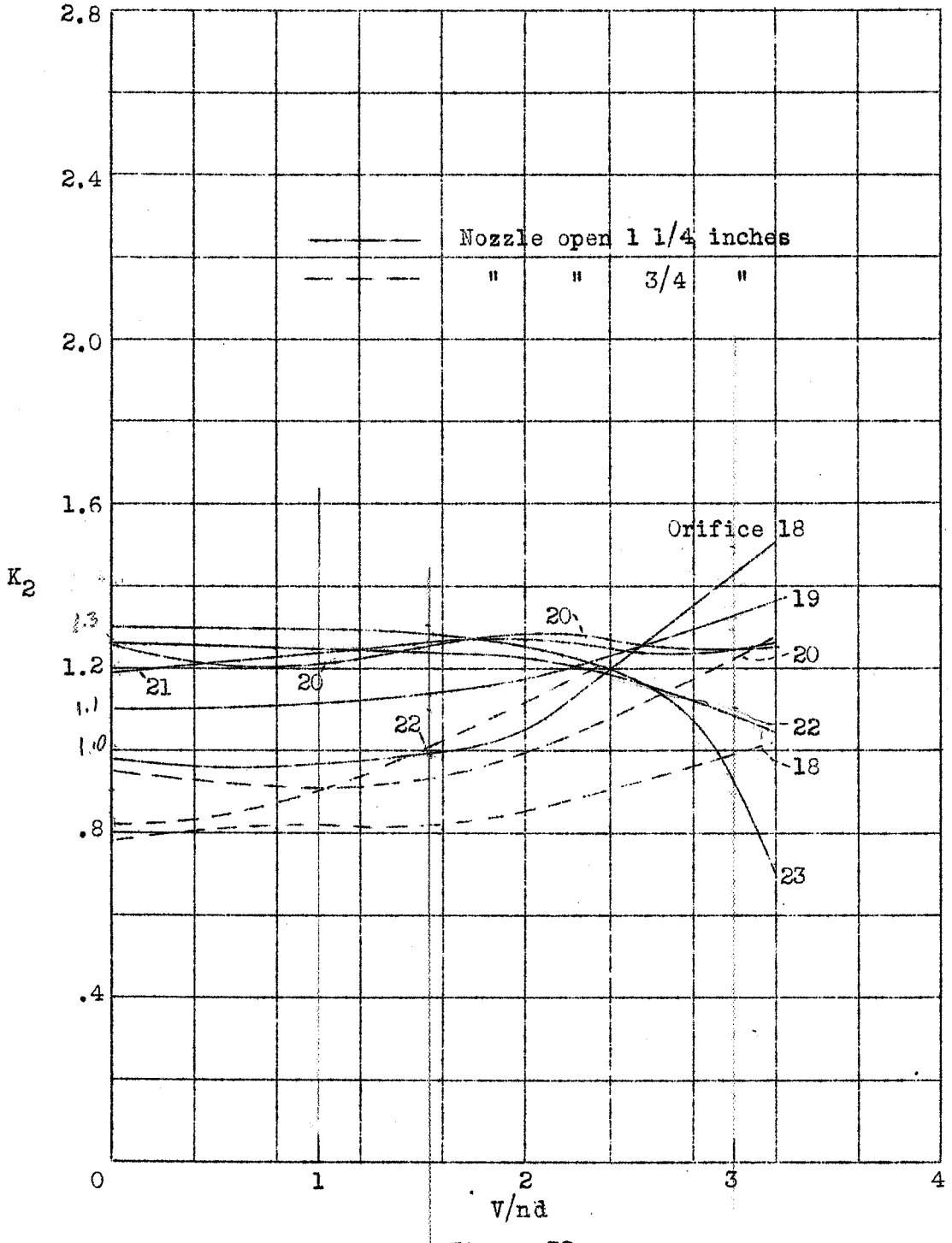
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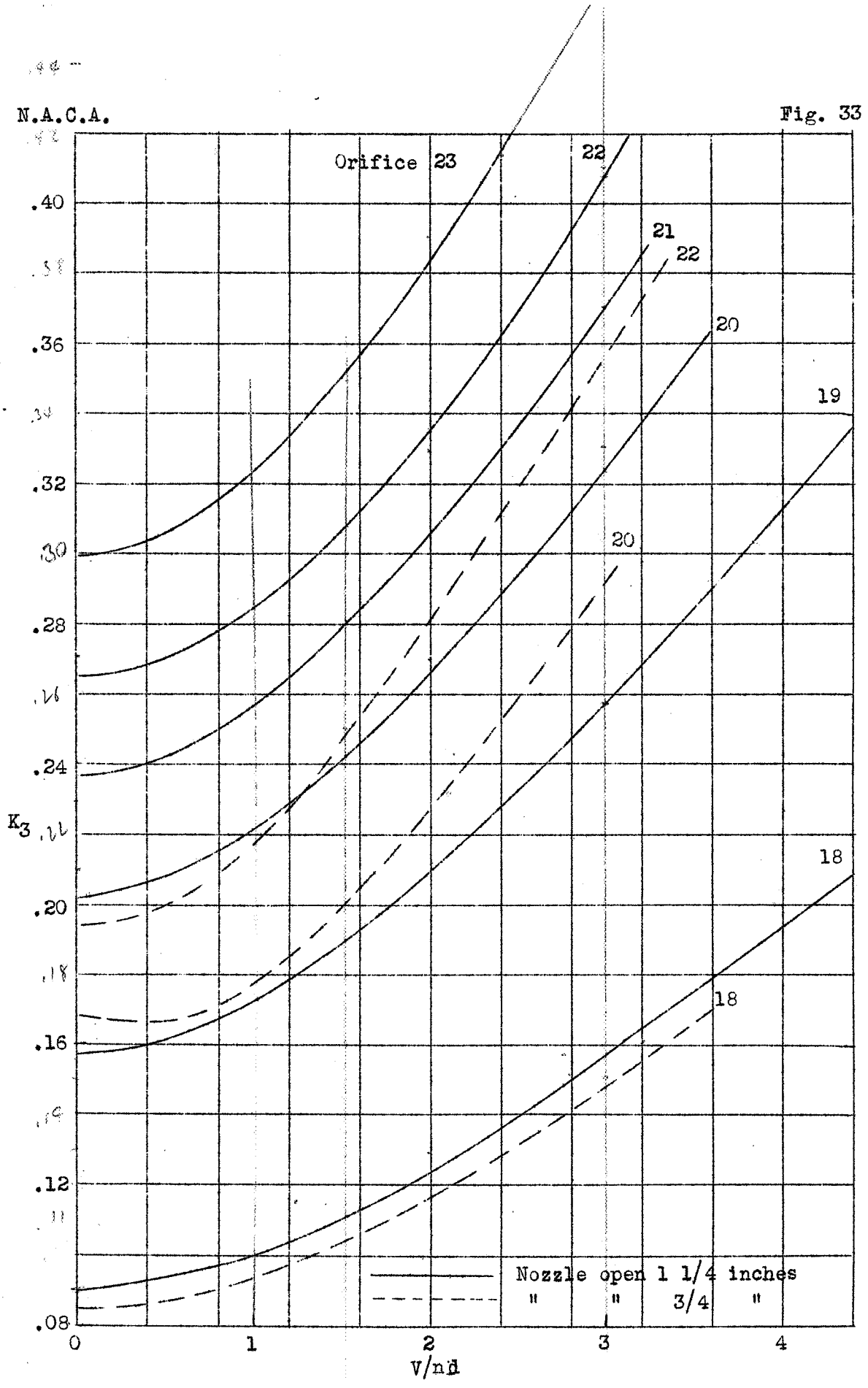
Figure 32.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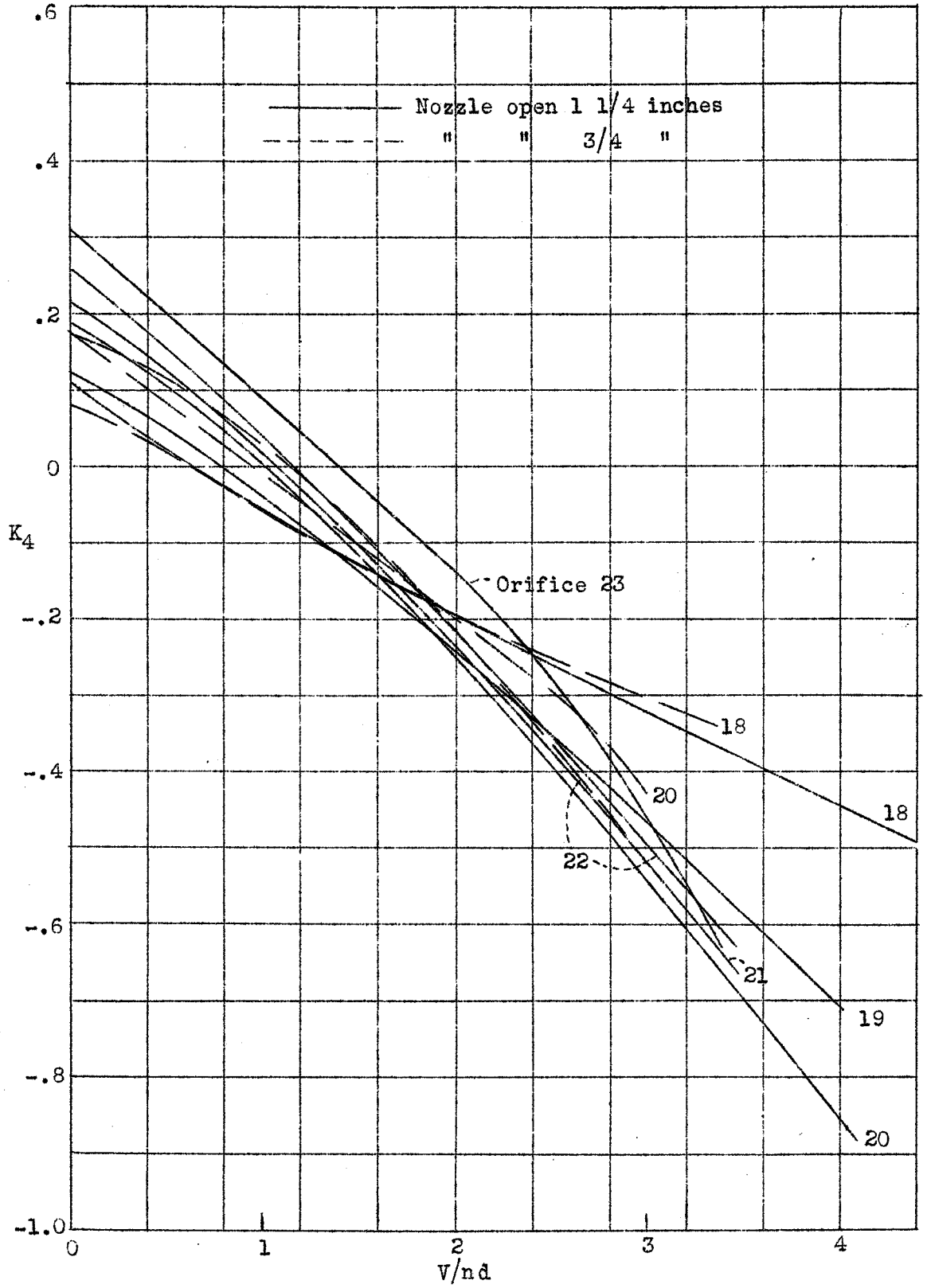
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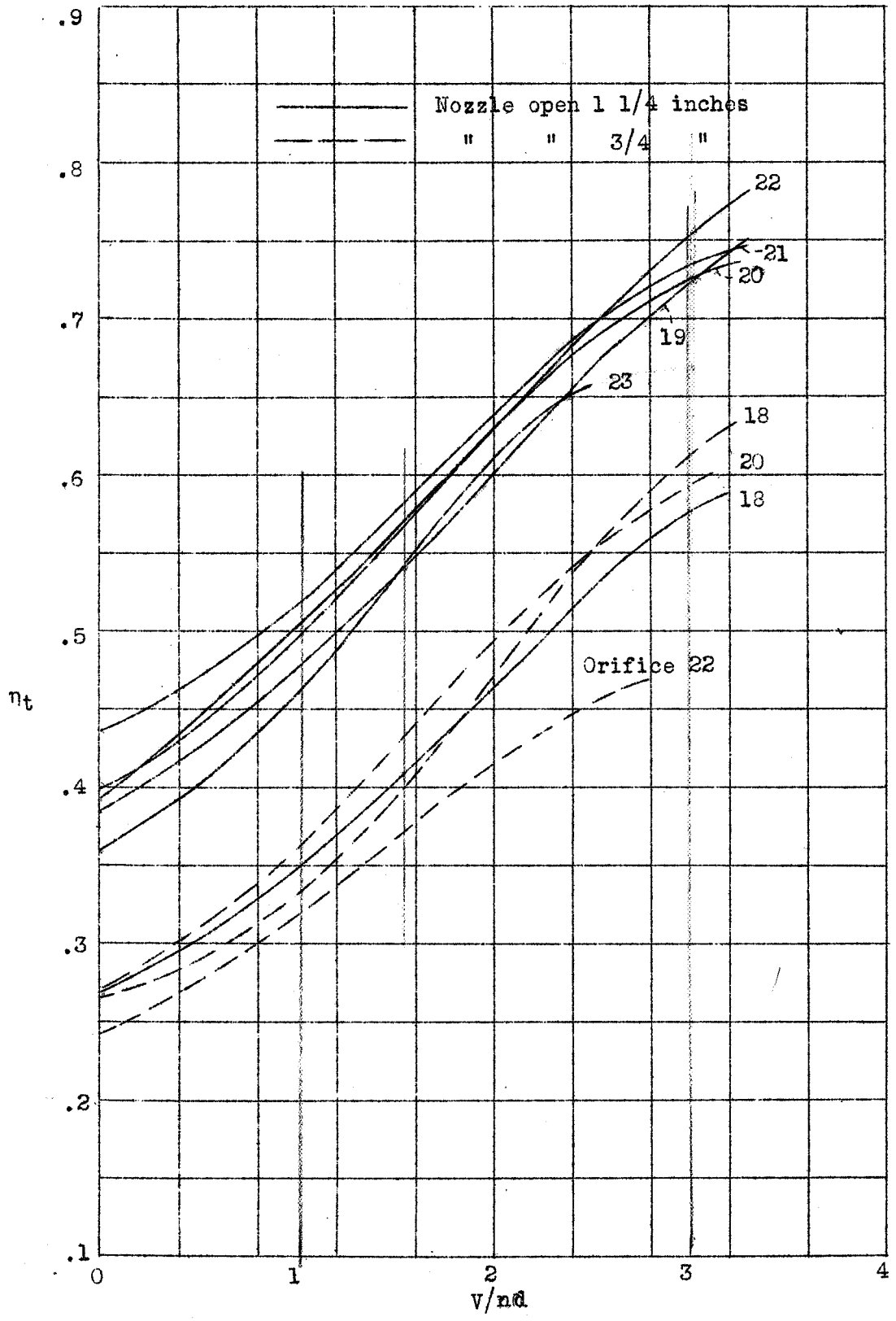
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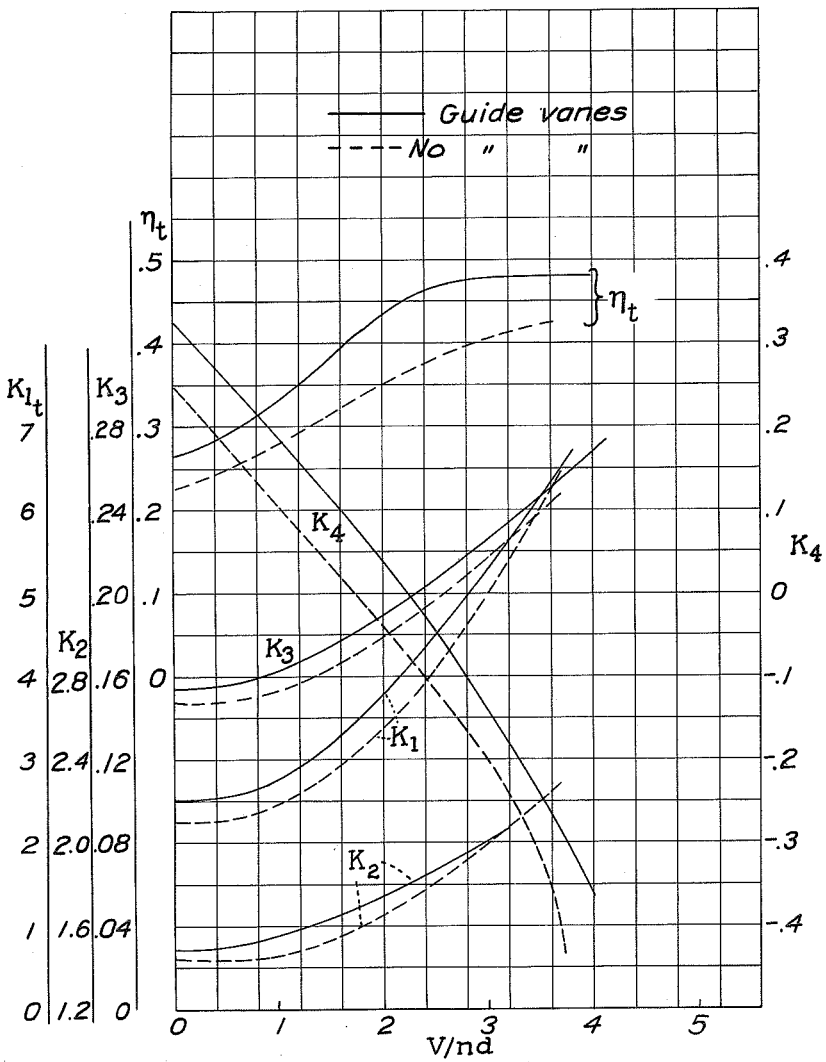

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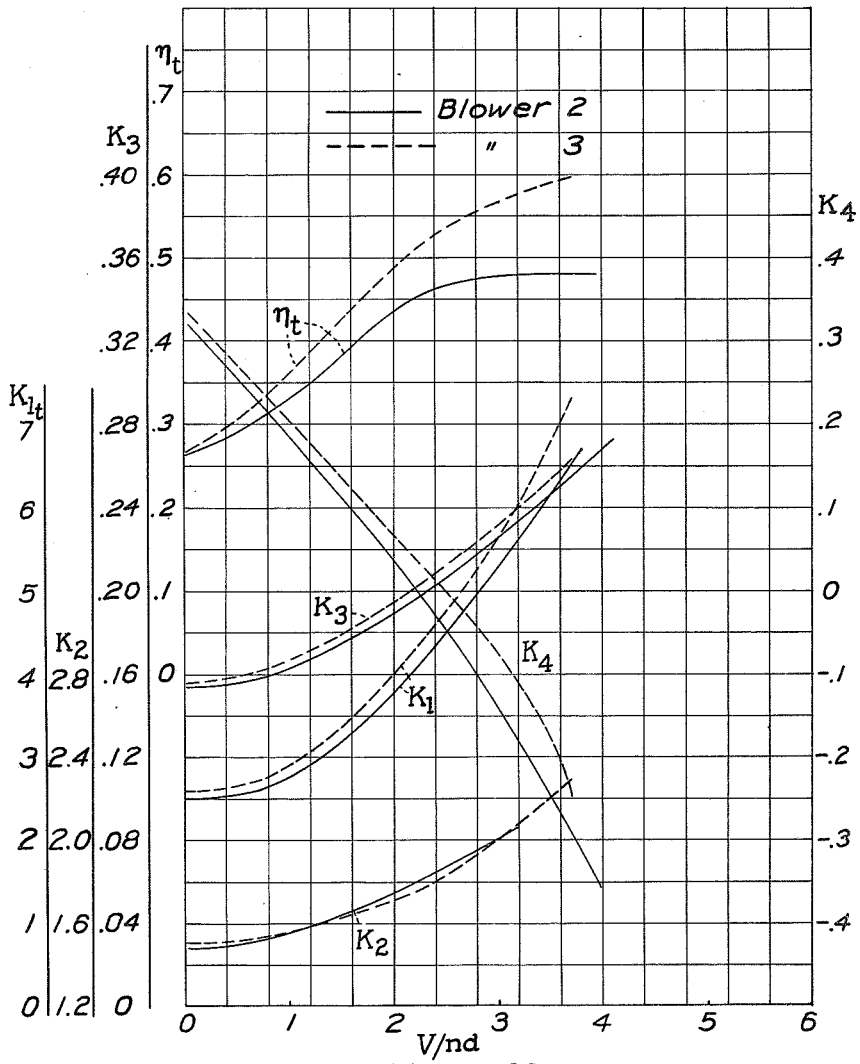

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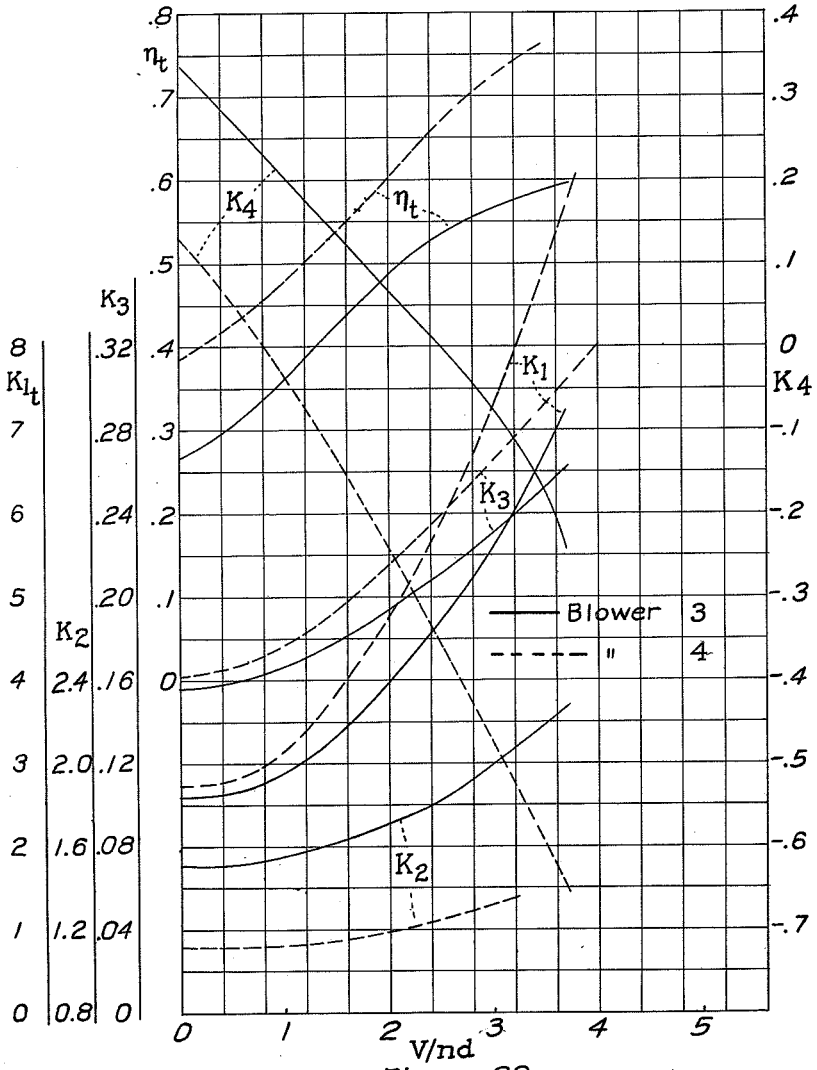

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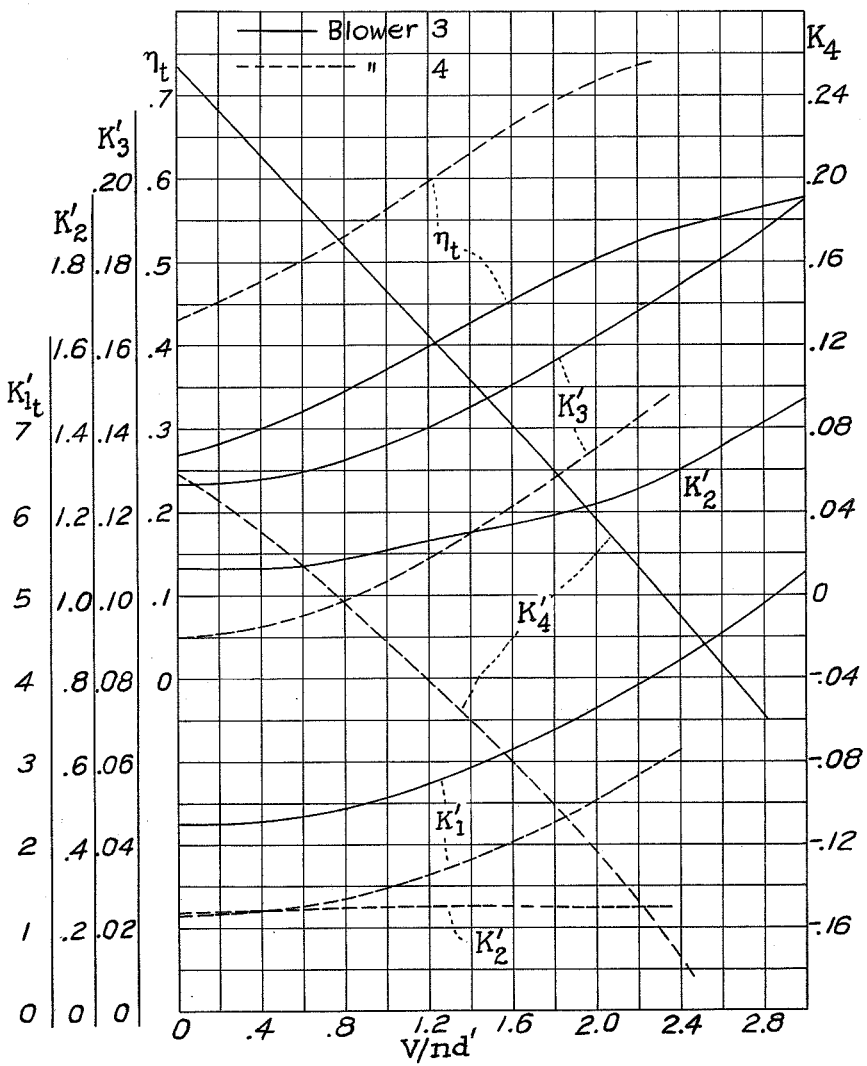

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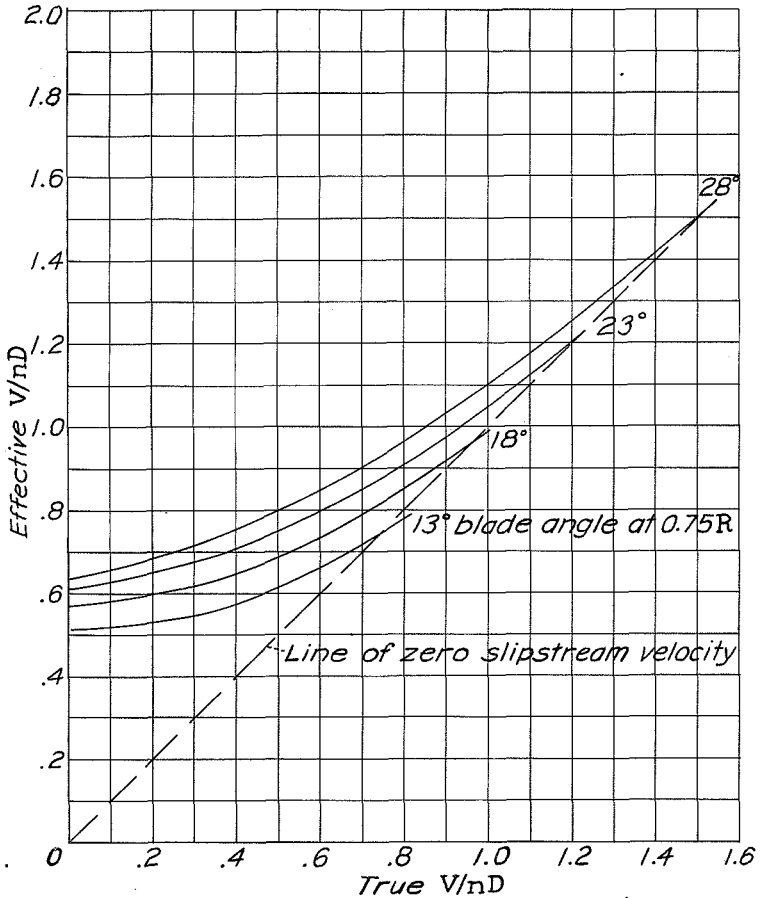
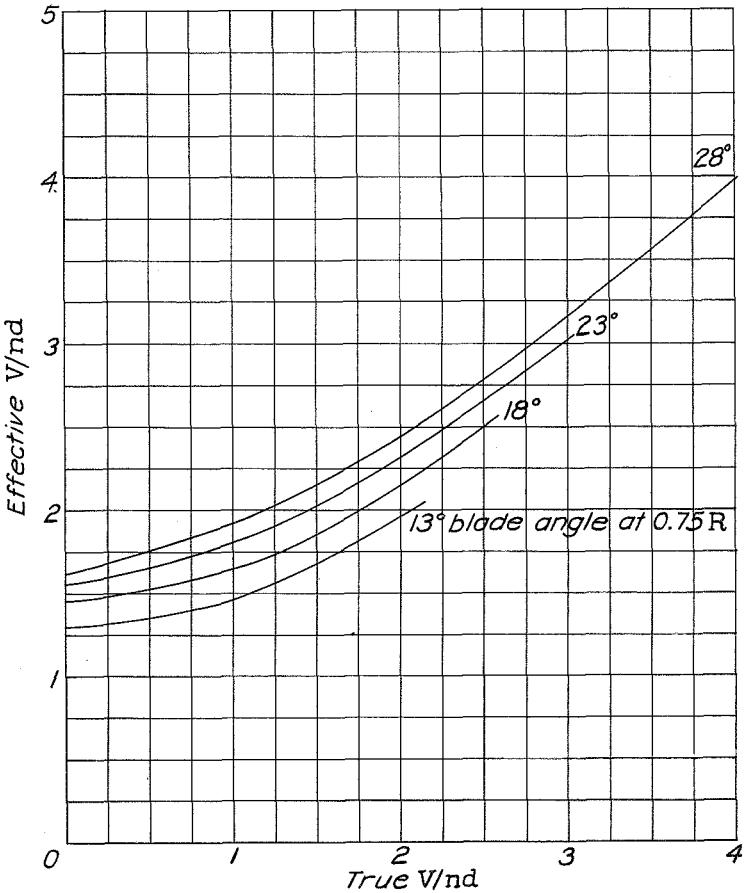


Figure 40

PROP 4412



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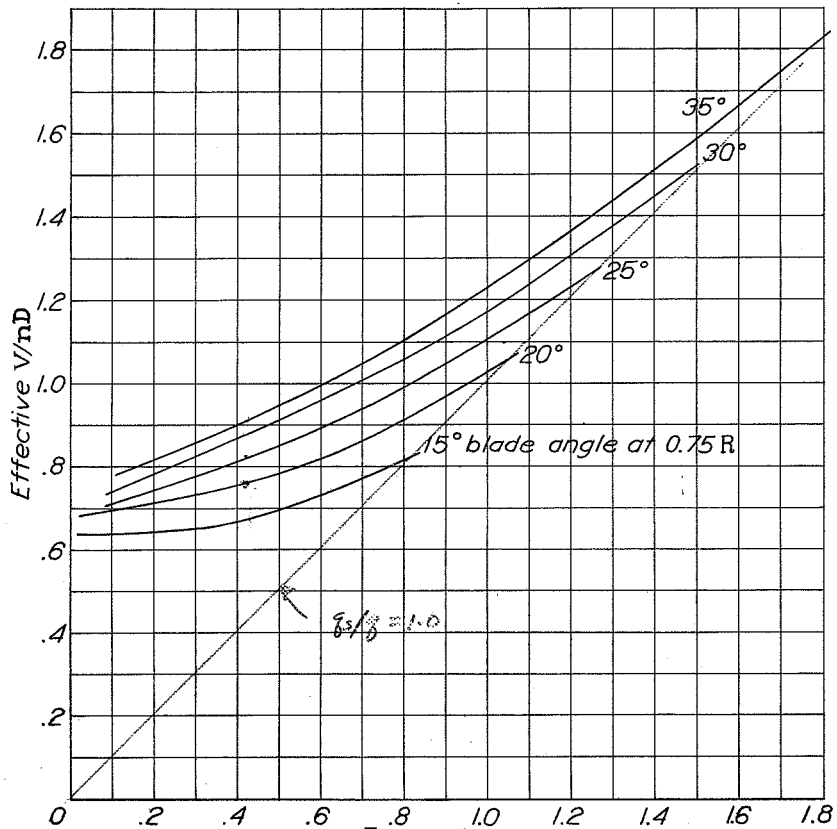


Figure 42

3-BLADE G101 PROP

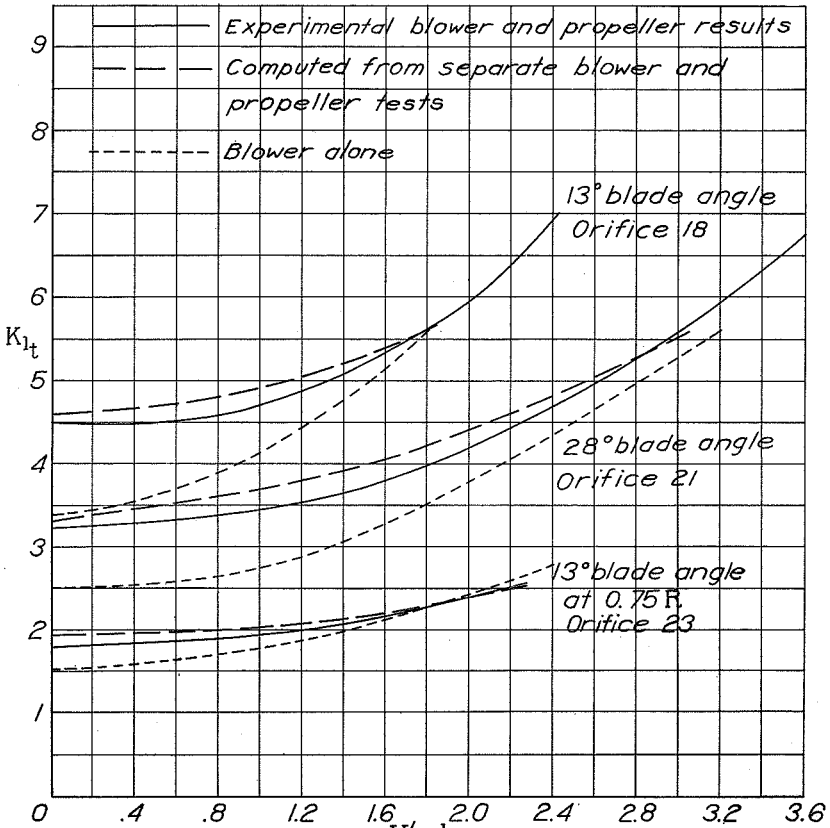
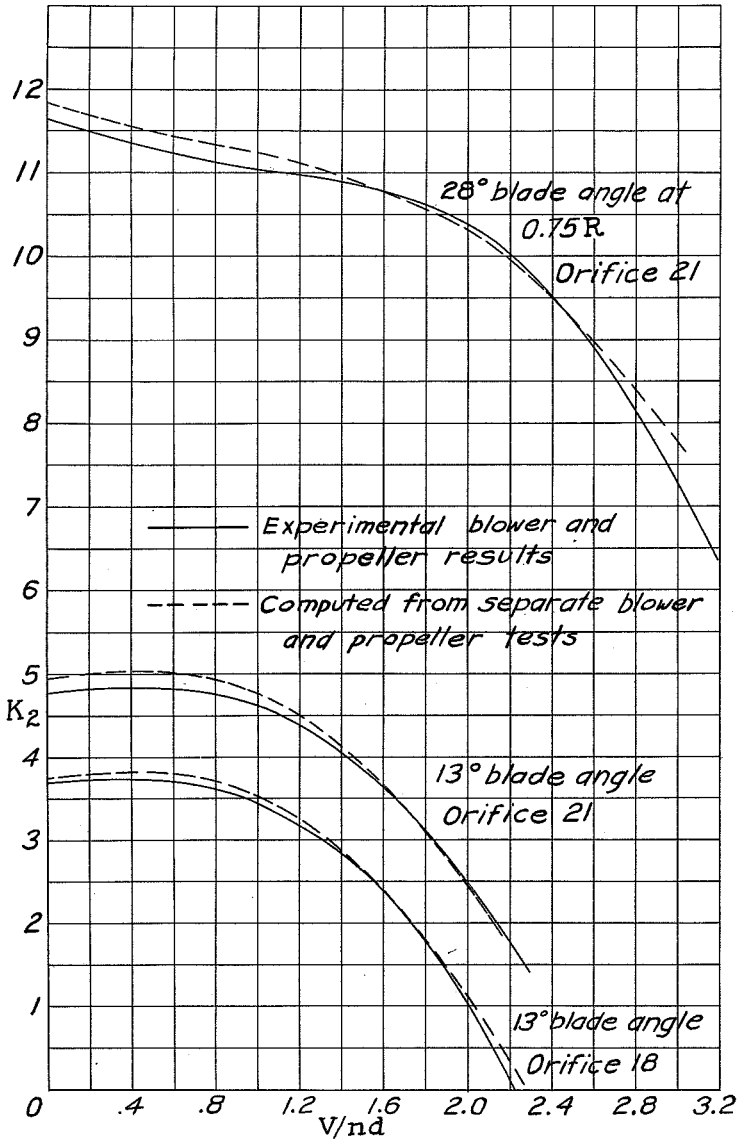


Figure 43

SEE Pg. 13



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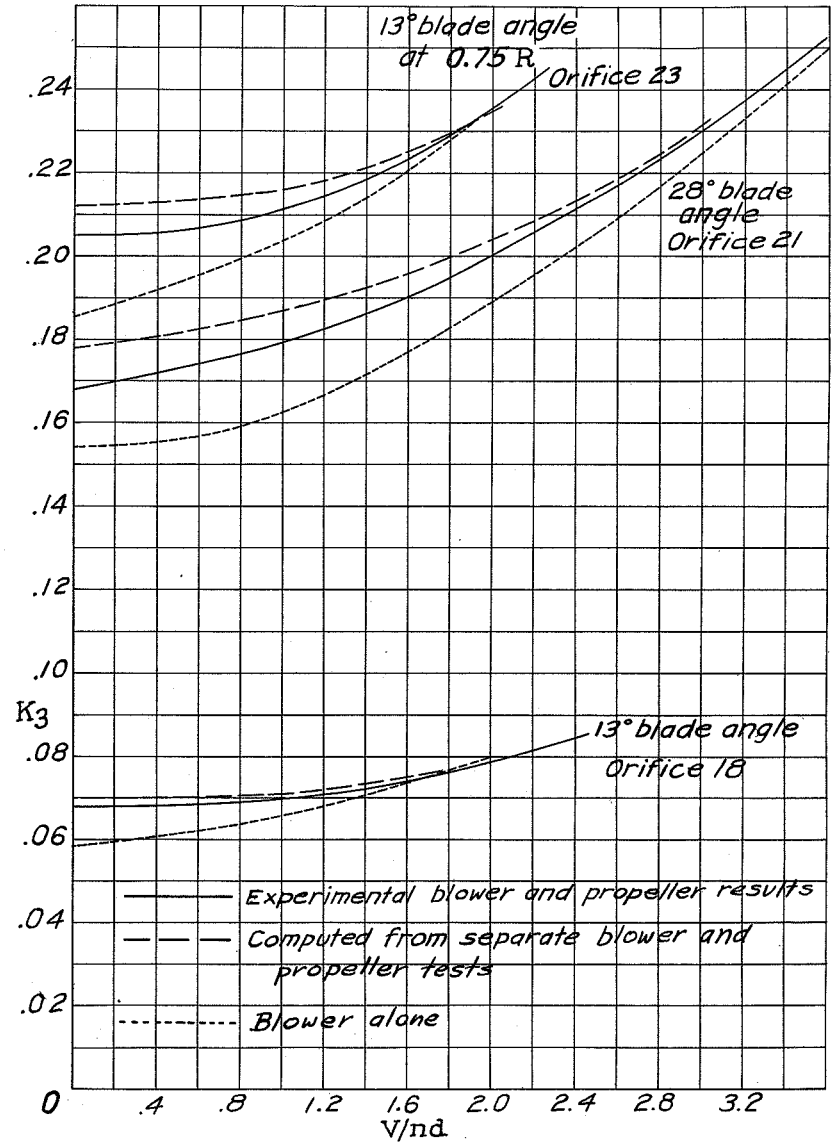
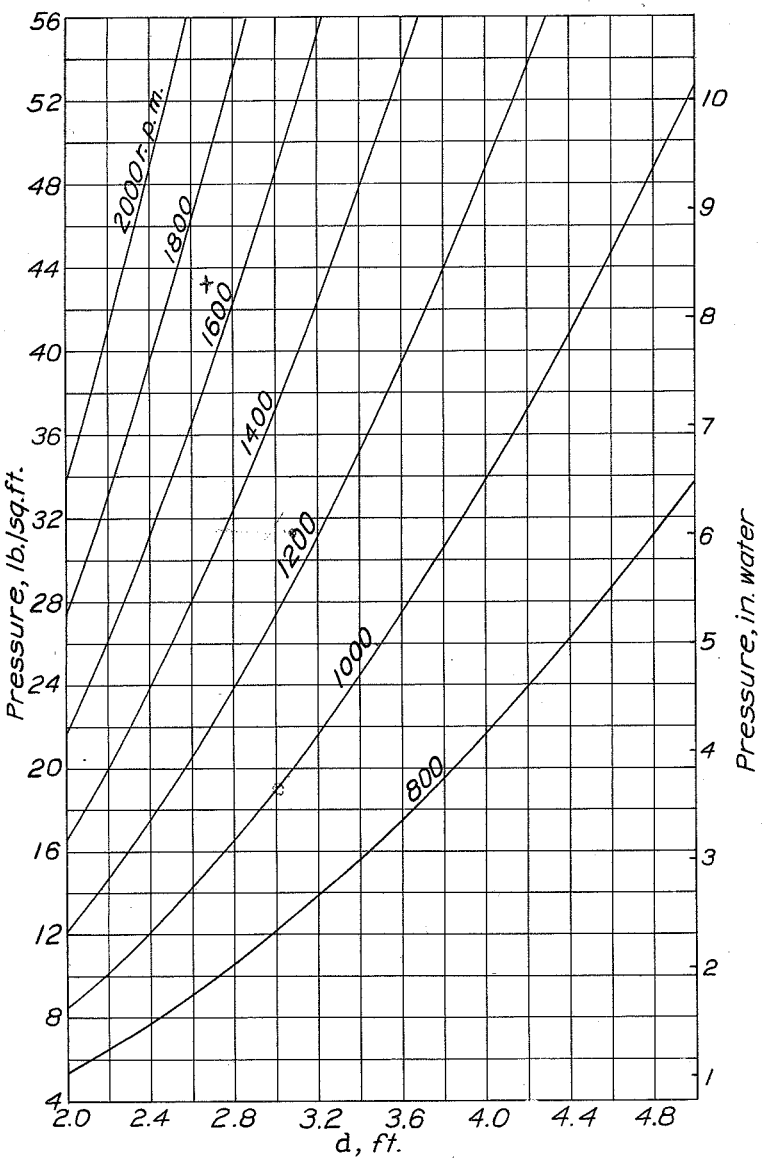


Figure 45



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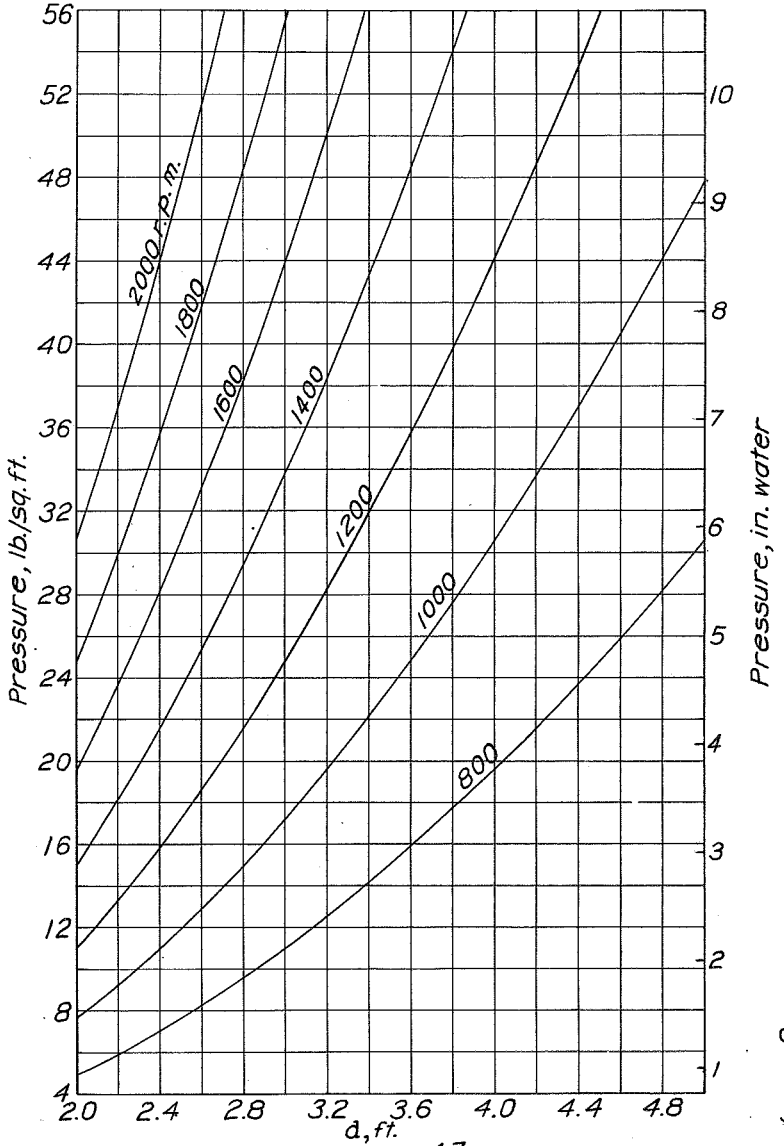

Figure 47