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INVESTIGATION FOR THE DEVELOPMENT OF A HIGH-SPEED ANTIAIRCRAFT TOW TARGET

By Eugene Migotsky

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Ordnance, Navy Department

INVESTIGATION FOR THE DEVELOPMENT OF A HIGH-SPEED ANTIAIRCRAFT TOW TARGET

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L-730

SUMMARY

An investigation has been conducted at the NACA full-scale tunnel for the purpose of developing a target which can be towed satisfactorily at high speeds.

The tests included drag measurements and visual observations of the stability characteristics of several full-size and 1/3-scale models of sleeve-type tow targets. A few tests were also made to determine the stability characteristics of a rigid-type tow target. The effects of fabric porosity on the drag and stability characteristics of the targets were investigated. Fins were added to some of the targets in an attempt to improve their stability characteristics.

The drag coefficients obtained for the currently used targets were found to be excessively high. Reducing the fabric porosity reduced the drag but also decreased the stability of the targets. The addition of fins to sleeve-type targets did not provide satisfactory stability. In general, the English type target, which has a tail diameter larger

than the nose diameter and restricts the major portion of the air leakage to the blunt tail, was found to be the most satisfactory of the sleeve-type targets. The rigid-type target, which has a much lower drag than any of the sleeve-type targets, should possess satisfactory stability for high-speed towing.

INTRODUCTION

The tow targets currently used by the Navy have become inadequate for realistic antiaircraft training. These targets have an excessive drag which greatly reduces the speed of the towing airplane and imposes such high loads upon the existing towing equipment that satisfactory towing cannot be obtained at speeds greater than 150 miles per hour. In order to develop a high-speed antiaircraft target capable of being towed in flight at 300 miles per hour indicated airspeed with suitable stability, an investigation was conducted at the request of the Bureau of Ordnance, Navy Department, in the NACA full-scale tunnel.

A summary of previous experimental investigations of tow targets by the Navy Department is given in reference 1. The present investigation included drag measurements and observations in the wind-tunnel of the flight characteristics of several full-size tow targets currently used by the Navy and of a full-size open-nose streamline target designed at the LMAL. In addition, 1/3-scale models of several sleeve-type tow targets were tested to establish the merits of different target designs. Fins of various sizes were added to one of the designs to determine their effectiveness in improving the stability of the model. A tow-target design, consisting of three plywood fins tapering almost to a point at the nose, was also tested. A study was made of the influence of fabric porosity on the drag and stability of tow targets of different shapes. Tests were also conducted to determine the relative merits of different tow-target fabrics that were submitted to the LMAL by several manufacturers.

To study the stability characteristics of a rigid tow target resembling an airship, a 1/16-scale model was tested in the NACA stability tunnel, and a 20-foot experimental target of this type was tested in the NACA 16-foot tunnel.

APPARATUS AND TESTS

Full-size sleeve-type targets. - Pertinent dimensions of the full-size Navy tow targets tested are given in table I. Figure 1 shows a sketch of the streamline target designed at the LMAL. This target was constructed from the fabric of a standard Mark XIV sleeve and had a rigid sheet-dural nose.

The full-size targets were mounted in the NACA full-scale tunnel by means of a 1/8-inch aircraft control cable extending from the target bridle upstream 150 feet to a pulley at the turning vanes and then downstream to the airplane support struts. The drag of the target was read directly on the wind-tunnel drag balance. Photographs of two of these targets in flight in the wind tunnel are shown in figures 2 and 3.

One-third-scale tow-target models. - Drawings are given in figure 4 of the 1/3-scale models which were tested to determine the relative merits of three basic tow-target shapes; namely, the currently used cylindrical type, the streamline form, and the truncated-cone shape recently developed in England. These targets were constructed from airplane fabric. The bridle was fastened to a 1/8-inch steel ring sewed into the nose of the sleeve.

The balance designed for testing the 1/3-scale models was placed on the side of the wind-tunnel center line so that the tests would not interfere with the wind-tunnel testing program. The models were towed by means of a 1/16-inch aircraft control cable that extended upstream 30 feet from the bridle of the target to a pulley mounted in the entrance cone and then down to a scale which measured the drag.

Tests were made to determine the effects of the air leakage through the fabric on the drag and stability of several of the target models. For these tests, the porosity of various sections of the fabric was reduced by brushing these portions of the fabric with light motor oil.

In an attempt to improve the stability characteristics of the streamline target (fig. 4(b)), fins were added to the sleeve. These modified sleeves are shown in figures 5(a) and 5(b). A tow-target design, consisting of three plywood fins tapering almost to a point at the nose (fig. 5(c)), was also tested. Visual observations were made to study the stability characteristics of these targets, but no drag readings were taken.

Various modifications (fig. 6) were made to an English type sleeve to determine the effects on the drag and stability characteristics of the sleeve resulting from minor changes in the basic geometric form such as the length of the sleeve, the shape of the tapered portion, and the size of the nose diameter. To simulate the impervious fabric of the tapered section of the English target, the tapered portion of these models was oiled and the flat circular tail piece was left dry.

The model shown in figure 6(c) was used for testing the relative porosity of the various fabrics. Samples of the materials were submitted for testing and the manufacturers' designations for them are as follows: Standard Navy tow-target cloth was used in the Mark XIV target and airplane fabric was used in the construction of the 1/3-scale models. The target drag was used as the criterion for comparison of the relative merits of the different fabrics submitted.

All the tests of the 1/3-scale tow-target models were conducted at the NACA full-scale tunnel at velocities from about 60 to 100 miles per hour.

Rigid-tow-target design. - A drawing of a 1/16-scale rigid-tow-target model, which was constructed of balsa wood and tissue paper, is given in figure 7. In order to obtain static stability, the center of gravity was moved forward (to a position about 0.3 of the length from the nose) by placing weights in the nose.

Tests to determine the stability characteristics of this model were conducted at the NACA stability tunnel, which is of the closed-throat type. The model was mounted in the wind tunnel by a fish line extending from the nose of the model about 10 feet upstream and attached to the upper wall of the tunnel throat. Visual observations of the flight of the model were made through a glass panel in the test section. Tunnel speeds up to about 150 miles per hour were used for these tests.

Tests of a 20-foot experimental target of this type were conducted at the NACA 16-foot tunnel. This target was constructed by the Navy and was geometrically similar to the model shown in figure 7. The location of the center of gravity, however, was approximately 0.5 of the target length from the nose. These tests were made to determine whether the target was stable with this rear center-of-gravity location.

The target was mounted in the wind tunnel by means of a 3/32-inch aircraft control cable extending from the target nose to the upper surface of the entrance cone. This setup is shown in figure 8. Visual observations were made of the flight of the target at airspeeds up to about 100 miles per hour.

RESULTS AND DISCUSSION

Full-size sleeve-type targets. - The measured drags of the full-size Navy tow targets tested have been plotted against indicated sea-level airspeed in figure 9. These same results are shown replotted in the form of drag coefficients in figure 10 where the drag coefficient, based on frontal area, is defined as

$$C_{D_f} = \frac{D}{\frac{\rho}{2} V_o^2 S_f}$$

where

D	drag
ρ	air density (0.00238 slug per cubic foot at sea level)
V_o	free-stream velocity
S_f	maximum frontal area

The drag coefficients vary between 1.15 and 1.48 for the range of test velocities, which is about in agreement with flight-test data. These values are about 10 times higher than would be expected from skin friction alone; in fact, they exceed the value of the drag coefficient for a flat circular disk normal to the wind stream, which is about 1.11 (reference 2). The high drag of these targets is probably associated with the energy required to pump the air through the fabric. If the entire dynamic pressure $\frac{\rho}{2} V_0^2$ is lost forcing a volume Q of air per second through the fabric, the resulting drag force is $\rho Q V_0$ and the corresponding drag coefficient, $2Q/V_0 S_f$. For example, if the leakage quantity were such that the entrance velocity was one-half the free-stream velocity, the resultant contribution to the total drag coefficient would be 1.0.

No drag measurements are presented for the streamline target designed at the LMAL. In the first tests of this target it failed to inflate, except at the tail. The fabric behind the nose and over most of the length remained wrinkled and contracted so that the passage through it was only about 1 square foot in cross section. A sketch of the peculiar shape taken by the target is given in figure 11. This shape results from the leakage of air through the fabric.

In order to reduce the permeability of the fabric, it was soaked in water. When tested, it inflated completely.

The flight was very unsteady, however, being characterized by a snaking motion, especially toward the tail, accompanied by violent lateral oscillations of the target as a whole. Due to these oscillations, no reliable drag readings could be taken; visual observations of the balance, however, indicated that the drag was about one-half to one-third that of the Mark XIV standard target.

One-third-scale models. - The drag coefficients of the three basic tow-target shapes - cylindrical sleeve (Mark XIV), streamline sleeve with ring nose, and English low-drag sleeve - are given in figure 12 for the dry-fabric condition. These results indicate that the latter two shapes are both superior to the Mark XIV. The drag coefficients obtained for the English low-drag sleeve were less than one-half the values obtained for the Mark XIV model.

The effect of decreasing the fabric permeability progressively from the nose to the tail on the drag coefficient of the Mark XIV model is shown in figure 13. At 70 miles per hour the drag coefficient of the dry model was 1.2, whereas with seven-eighths of the sleeve oiled the drag coefficient was reduced to 0.8. With this decrease in drag there was an accompanying decrease in stability. When the target was three-fourths (or more) wet, the oscillations were of such a nature that reliable drag readings could not be taken at the higher airspeeds.

In the oiled condition the streamline sleeve (fig. 4(b)) was unstable, even at the lower wind-tunnel velocities. An attempt was made to correct this instability by adding three-fin tail surfaces to the model. The small three-fin plywood tail (fig. 5(a)) proved entirely inadequate. Although the larger three-fin tail (fig. 5(b)) was somewhat more effective, it did not provide satisfactory stability, The failure of the fins to correct the instability is due to the fact that any righting moment that the fins may produce is not transmitted through the nonrigid fabric; consequently, the tail of the target retains its snaking motion. The target model shown in figure 5(c), consisting of fins only, may be considered as the limiting case resulting from increasing the fin area. The path described by this model in flight was approximately a cone with the pulley in the support strut as the apex. The peculiar nature of this flight may have been the result of a slight twist or misalinement of the fins and improper center-of-gravity location.

The results of the tests of the English low-drag sleeve were more satisfactory. When the fabric was dry, the drag coefficients were about one-half the values obtained with the dry Mark XIV model. The results of tests made with the tapered section of the target oiled are shown in figure 14. The drag coefficient of this target at the higher wind-tunnel speeds (about 100 miles per hour) was 0.36 or about

28 percent of the drag of the dry Mark XIV model at the same velocities. The stability of this model was much more satisfactory than any of the other models tested in the oiled condition. At the lower airspeeds, the flight of the model was characterized by some tail shaking and lateral oscillations of the target as a whole. The motions, however, were not of a violent nature. As the airspeed was increased, the lateral oscillations of the entire target almost disappeared and the tail shaking was materially reduced.

Since the area presented to the gunner by this target is small in comparison to the original Mark XIV sleeve, several larger targets of the same general construction were tested to determine the effect of increasing the length of the sleeve while keeping the same nose and tail diameters constant. The results of these tests are shown in figure 15. The change in drag coefficient with increasing length is small. At 100 miles per hour, the drag coefficient of the 10-foot target is 0.02 greater than the corresponding value for the English low-drag sleeve (length = 4 feet 11 inches). This increase is negligible, however, when compared to the increase in side area presented to the gunner.

The results of tests made to determine the effects of changing the shape of the tapered portion and nose diameter of the $6\frac{1}{2}$-foot model of the English type target are presented in figures 16 and 17. Changing the shape of the tapered portion reduced the drag coefficient of the dry target about 0.03 but had little effect on the drag of the oiled sleeves. Reducing the inlet opening reduced the drag coefficient of the sleeve by 0.05. This reduction in drag is due to the reduction in the quantity of air entering the sleeve, which results in a smaller quantity of air leaking out through the fabric.

In general, changing the length of the sleeve, the shape of the tapered section, and the nose diameter had little effect on the stability characteristics of the English type target. Assuming that the drag force remains essentially constant for small displacements of the sleeve from the neutral position, the restoring moment is a direct function of the moment arm of the drag force which is a maximum when the drag is located at the tail of the target.

The drag coefficients, based on maximum frontal area, for the English type sleeves made from the different fabrics are plotted against indicated airspeed in figure 18. No results were obtained for the rayon fabric A since its porosity was too great and only a small portion at the rear of the sleeve was inflated. The drag coefficients of the targets constructed of the other materials (fabrics B, C, and D) varied between 0.42 and 0.50, which indicates that these fabrics have a lower porosity than the airplane fabric used in previous tests which, in the dry condition, had a drag coefficient of 0.60. Fabric C is slightly superior to the others. The porosity of the target cloth used in the Mark XIV targets is about the same as that of the airplane fabric and is much greater than the porosity of fabrics B, C, and D.

It should be noted that there may be some velocity effect on the porosity of the fabric, and the drag results may not apply exactly to a full-size target being towed at high speeds. From tests of various fabrics by MacLennan (reference 3), the quantity of air flowing through the fabric increases with pressure drop across the fabric at a different rate for different fabrics. It is believed, however, that the relative merits of the fabrics as determined by these tests should not be affected greatly by scale effect.

Rigid tow-target design. - The use of a rigid, streamline body, resembling an airship, for high-speed towing offers the advantages of much lower drag than the sleeve-type targets and stability through the use of fins.

Tests of the 1/16-scale rigid-tow-target model (fig. 7) in the NACA stability tunnel showed that this model was very stable at all wind-tunnel speeds. As the airspeed increased the steadiness of the model also increased and, at velocities over about 100 miles per hour, the model assumed an extremely steady attitude in the throat of the wind tunnel. No drag measurements of this model were made. It is believed, however, that the drag coefficient of the target, based on maximum cross-sectional area, is of the order of 0.09, which is about one-fifteenth that of the Mark XIV sleeve.

The 20-foot experimental target tested in the NACA 16-foot tunnel was found to be stable through the range of airspeeds tested (about 70 to 100 miles per hour) but exhibited a rotational tendency which wound up the cables attached to the target. This was probably due to a slight twist in the tail surfaces and should not prove to be very serious. Since perfect alinement of the fins is difficult to obtain, it is suggested that an effective swivel be incorporated in the design to compensate for the resulting rotation.

The addition of fins to this type of target is necessary inasmuch as bodies of this shape are aerodynamically unstable. An analysis has been made of the fin area required to obtain neutral stability for this type of target. The results of this analysis are presented in figure 19 as curves of total fin area required against target length for targets which are geometrically similar to the model shown in figure 7.

To estimate from figure 19 the fin area required for a target of given length and center-of-gravity location, find the coinciding point of target length and center-of-gravity location and read to the left for the fin area.

In order to obtain the fin area required for a target having a tail with aspect ratio other than 3.25, the correction factor K can be applied by using the relation

$$S_t = K(S_t)_{A = 3.25}$$

where S_t is the total area of the four fins.

Since these results provide for neutral stability only and for a tow target of this type a fair degree of stability is desirable, it is recommended that the fin area obtained for neutral stability be multiplied by a factor of 1.5 to 2.0.

Towing cable. - In presenting the drag results of the tow targets, no consideration has been given to the drag of the cable which must be taken into account when estimating the horsepower required to tow the target. This cable drag would be materially reduced if a low-drag target such as the rigid type were used which permits the use of towlines of smaller size and less drag.

Experience has shown that cable length is an important factor in the stability of a towed body, and an analysis by Glauert (reference 4) indicates that a short wire is a factor which tends to produce instability. No difficulty should be encountered with the long towlines used in practice.

CONCLUDING REMARKS

1. The drag coefficients obtained for the full-size Navy tow targets were high and exceeded the value for a flat circular disk normal to the wind stream. This high drag was found to be due to high fabric porosity.

2. A tow target of the English type, which has a tail diameter larger than the nose diameter and restricts the major portion of the air leakage to the blunt tail, has about one-quarter the drag coefficient of the standard cylindrical sleeves and has adequate stability.

3. Reducing the permeability of the fabrics reduced the drag of all the targets tested but also decreased their stability. The stability of the English type targets was least affected by reductions in the fabric porosity. The cylindrical and the streamline sleeves, however, were unstable when the fabric was impervious.

4. Conventional fins to improve the stability of fabric targets are not effective due to the failure of the nonrigid fabric to transmit the stabilizing loads to the body.

5. A rigid-type tow target, resembling an airship, should have about one-fifteenth the drag of the Mark XIV target and sufficient stability for towing at high speeds.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 3, 1943.

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2. Diehl, Walter Stuart: Engineering Aerodynamics. The Ronald Press Co., rev. ed., 1936, p. 262.

3. MacLennan, A. M.: Air Permeability of Parachute Fabrics. Part I. Rep. No. Ch. 337, British R.A.E., Oct. 1942.

4. Glauert, H.: The Stability of a Body Towed by a Light Wire. R. & M. No. 1312, British A.R.C., 1930.

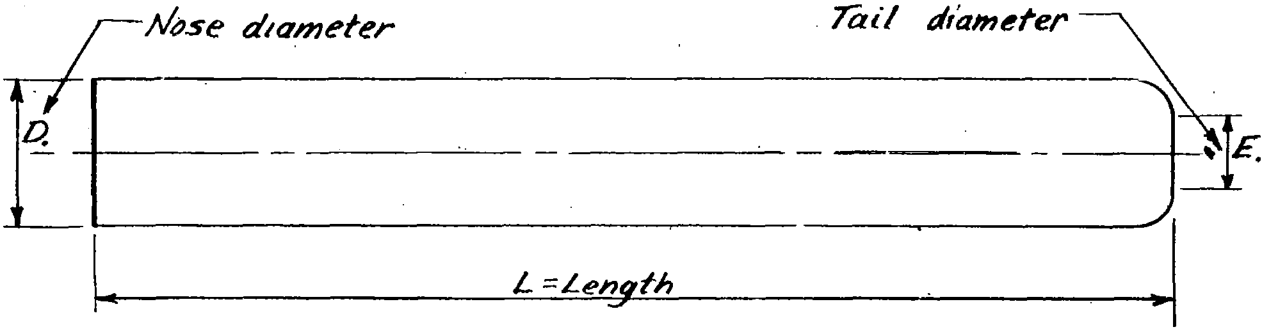

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Table I.

Target designation.	Nose construction	Nose diameter	Tail diameter	Length
Mark-XIV (standard)	Flexible ring	3'-8"	2'-0"	28'-0"
Mark-XIV (special)	Flexible ring	3'-9"	2'-0"	28'-10"
B-15*	Rigid ring	3'-3"	0'-9"	28'-6"
Mark-VII	Flexible ring	2'-7"	1'-8"	18'-8"

* Tail end made of extra-porous material

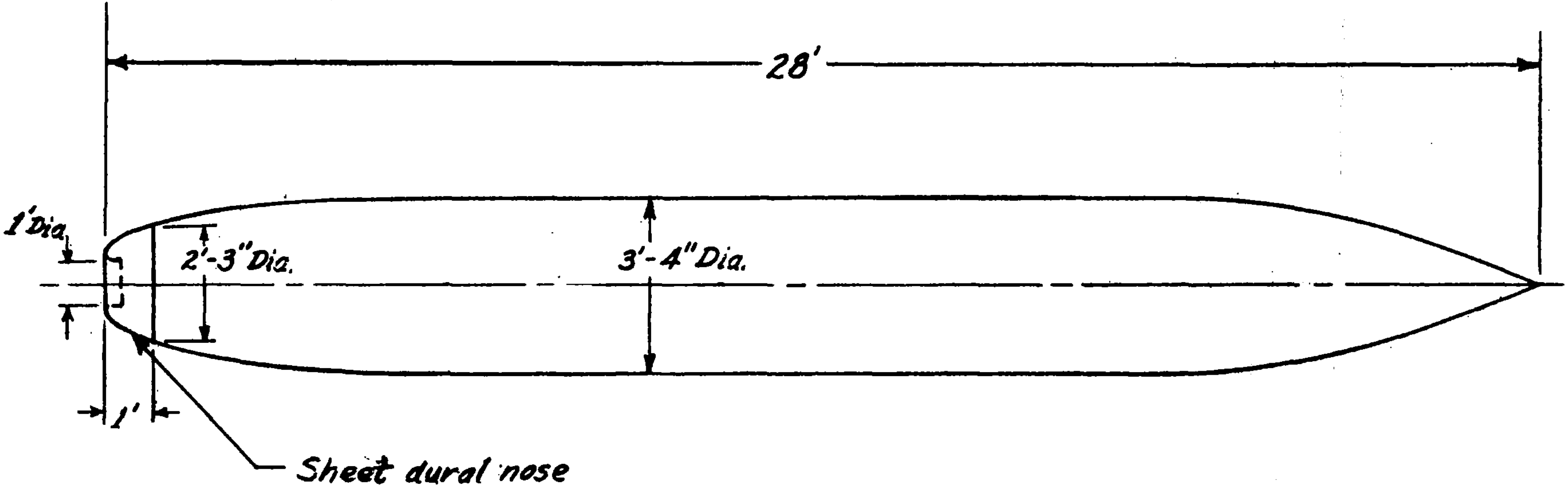

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Figure 1. - Sketch of full-size streamline target designed at the LMAL.

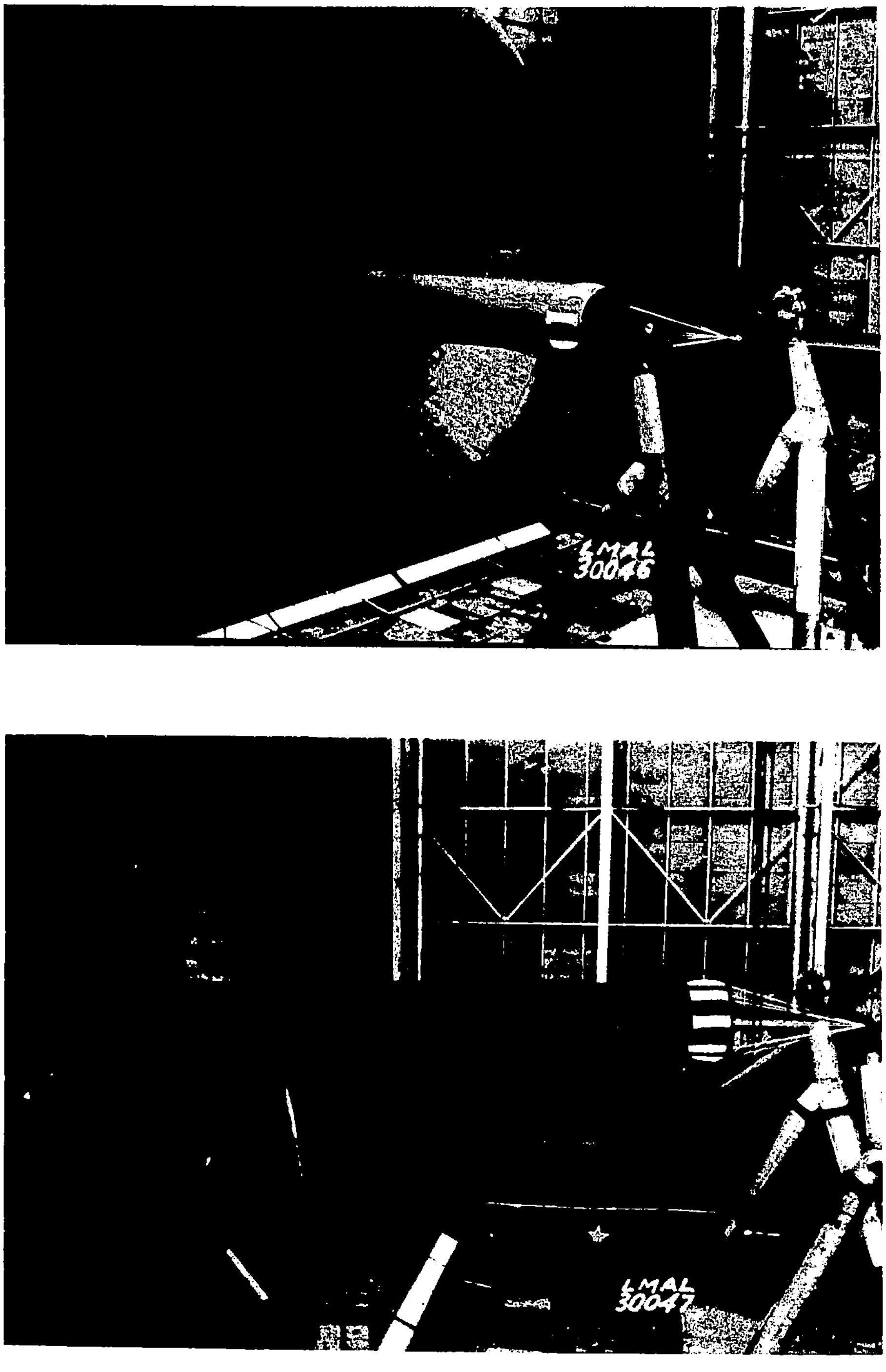


Figure 2.- Two views of the Mark-XIV (standard) tow target in the NACA full-scale tunnel.

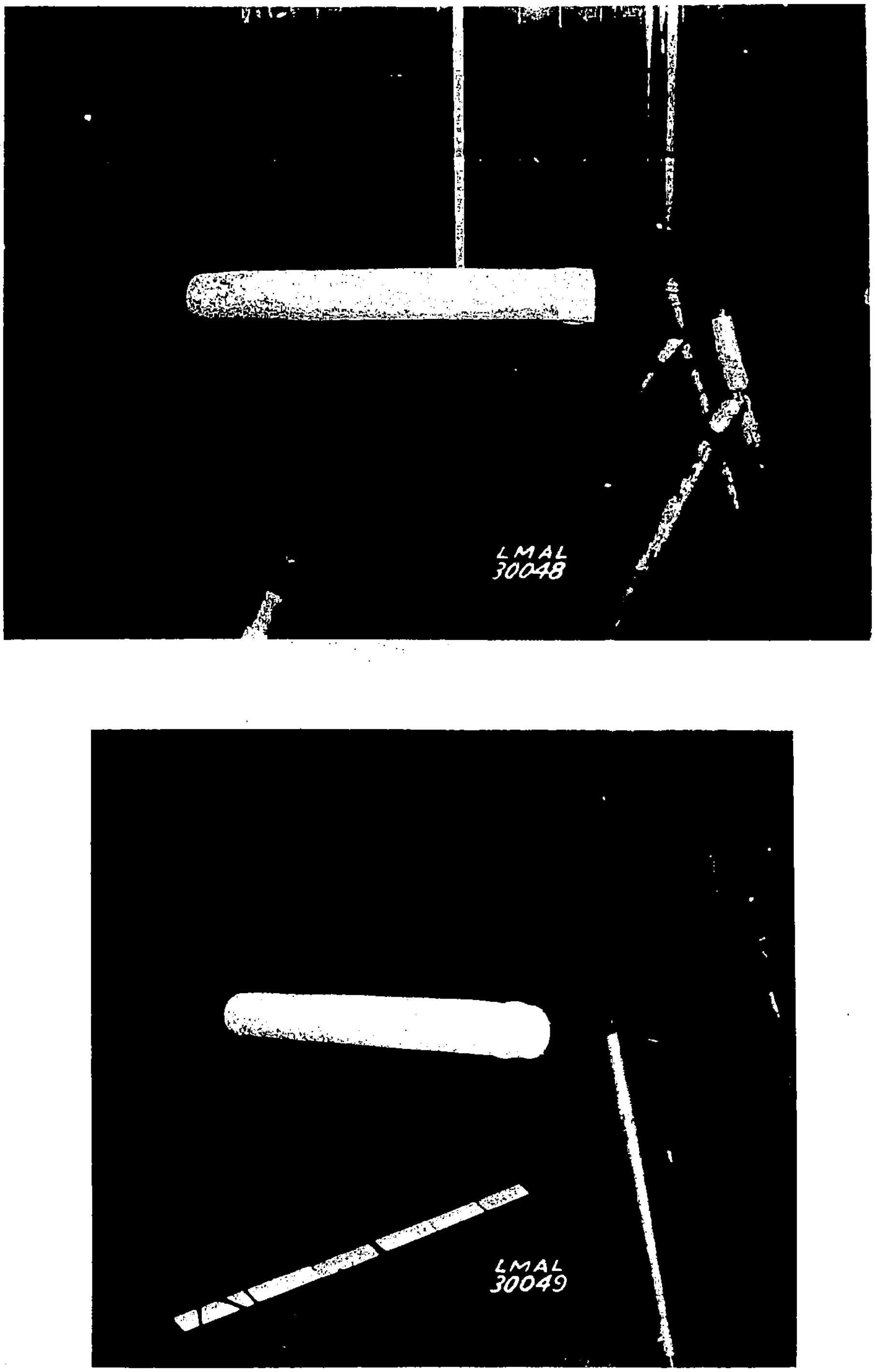
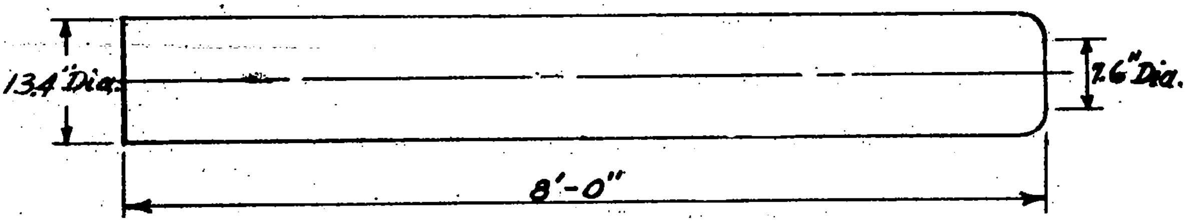


Figure 3.- Two views of the Mark-VII tow target in the NACA full-scale tunnel.



(a) Cylindrical sleeve.

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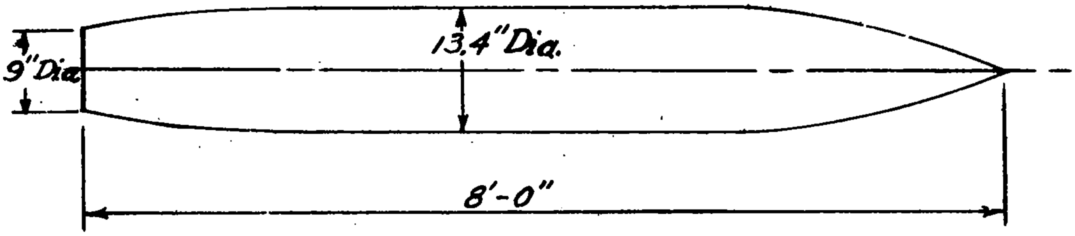
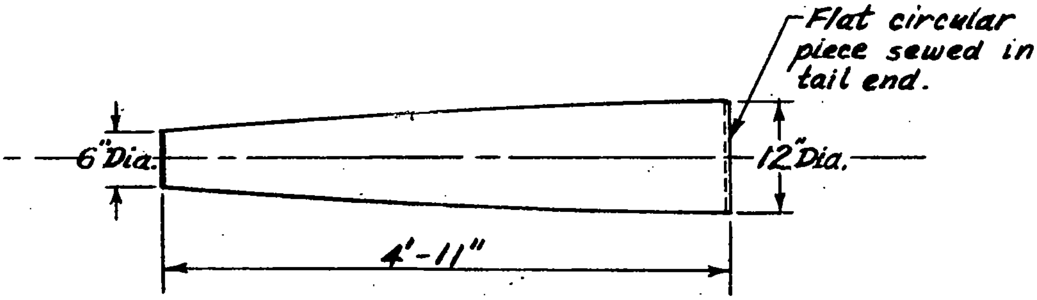
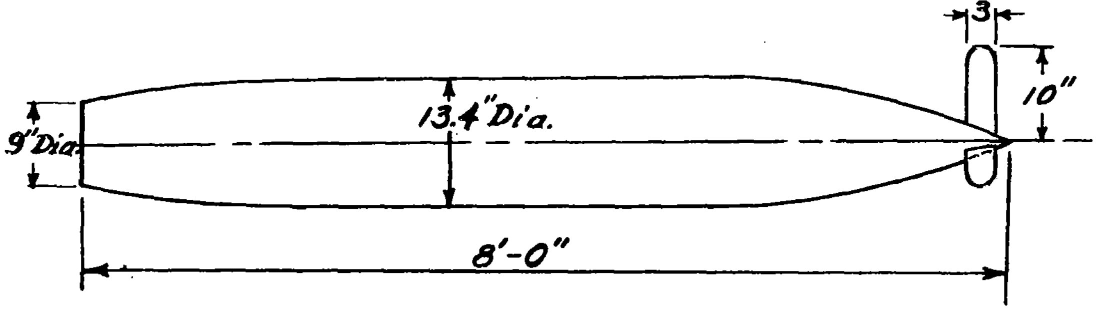


(b) Streamline sleeve with ring nose.

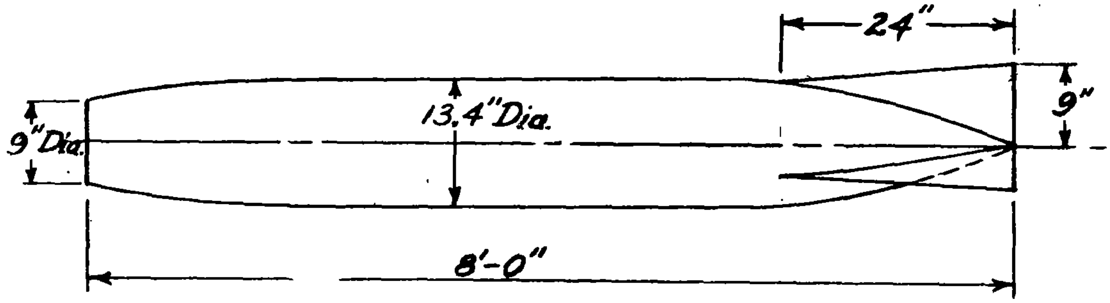


(c) English low-drag sleeve.

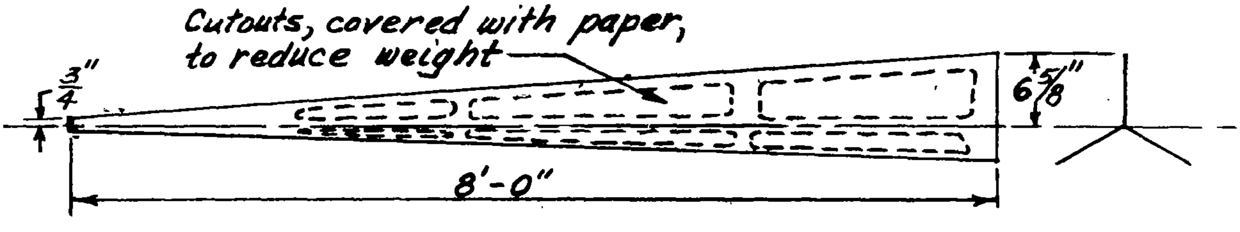
Figure 4. - One-third scale models of the three basic tow-target shapes.



(a) Streamline target with ring nose and small 3-fin plywood tail.



(b) Streamline target with ring nose and larger 3-fin paper covered tail.



(c) Three-fin plywood & paper target.

Figure 5. - One-third scale models of tow targets with fins.

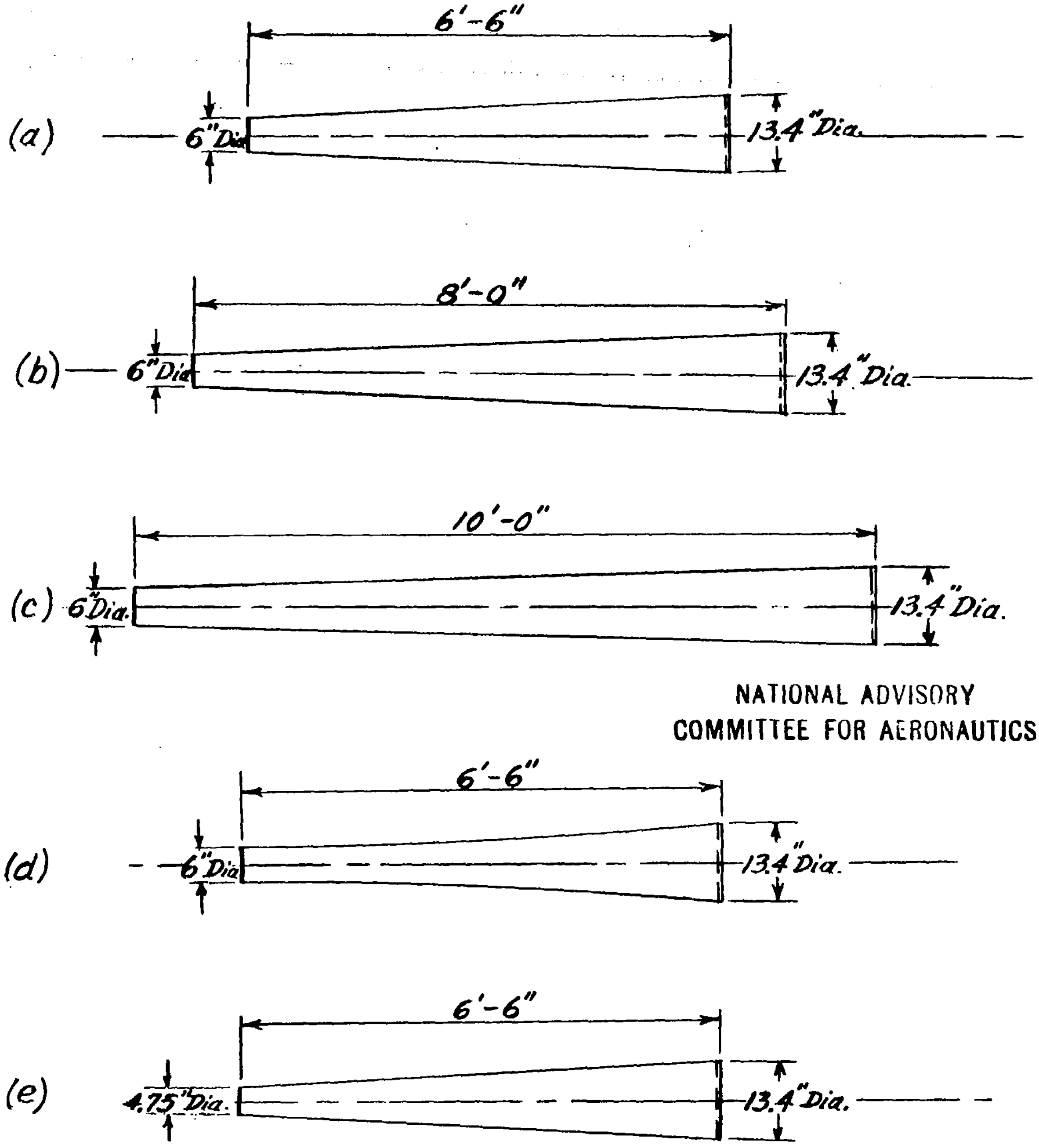


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Figure 6. - Modifications of the English type tow target.

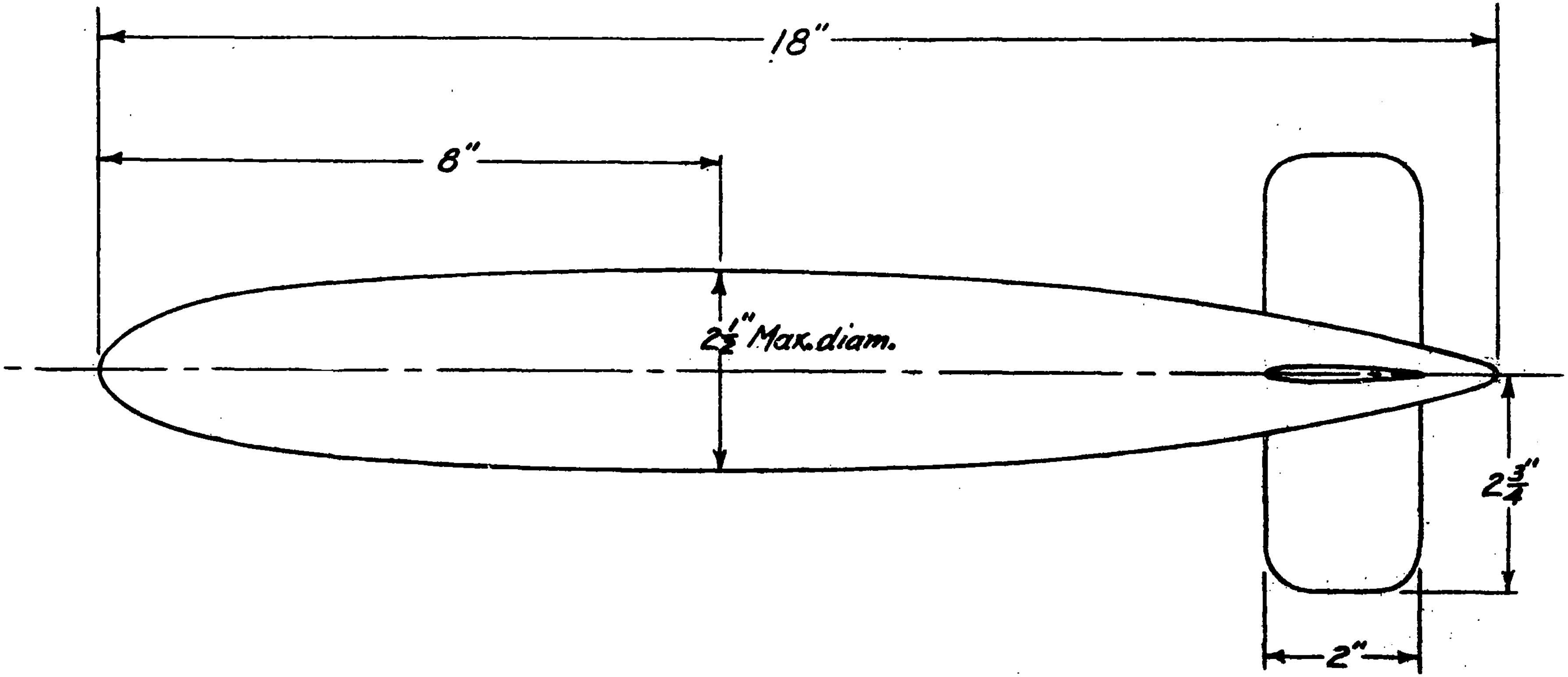

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Figure 7.- Dimensions of 1/16-scale rigid tow-target model.

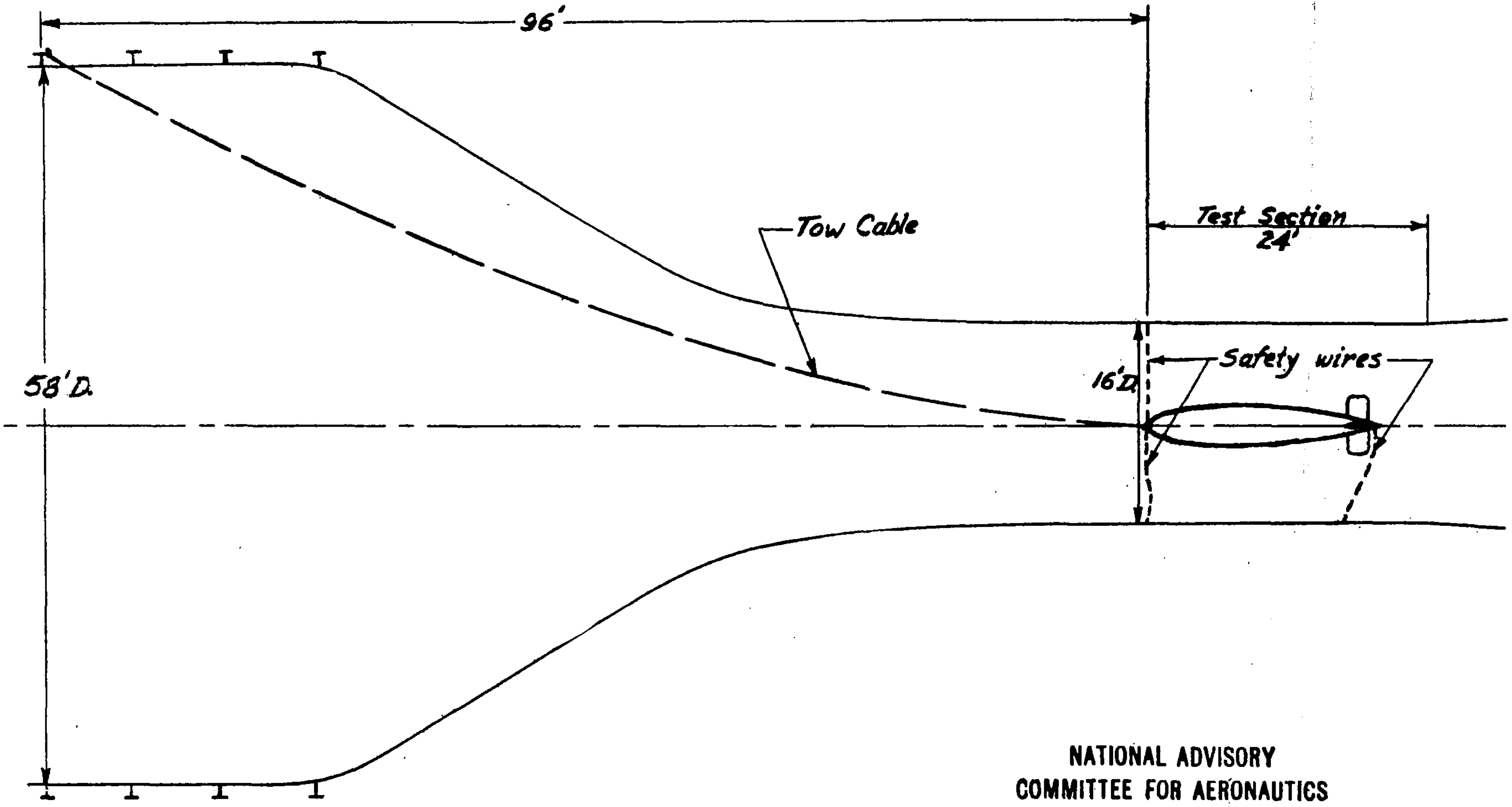

Figure 8. - Location of 20-foot rigid target in the LMAL 16-foot tunnel.

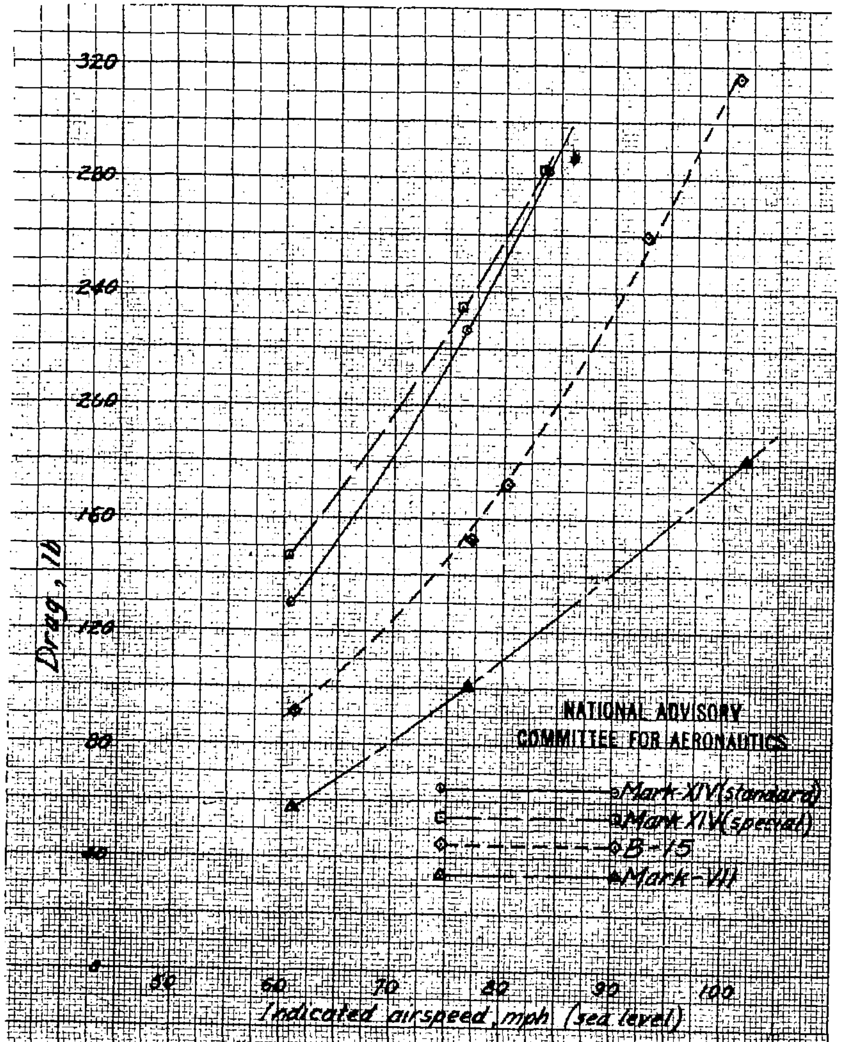

Figure 9. - Variation of drag with indicated airspeed for the full-size Navy tow targets.

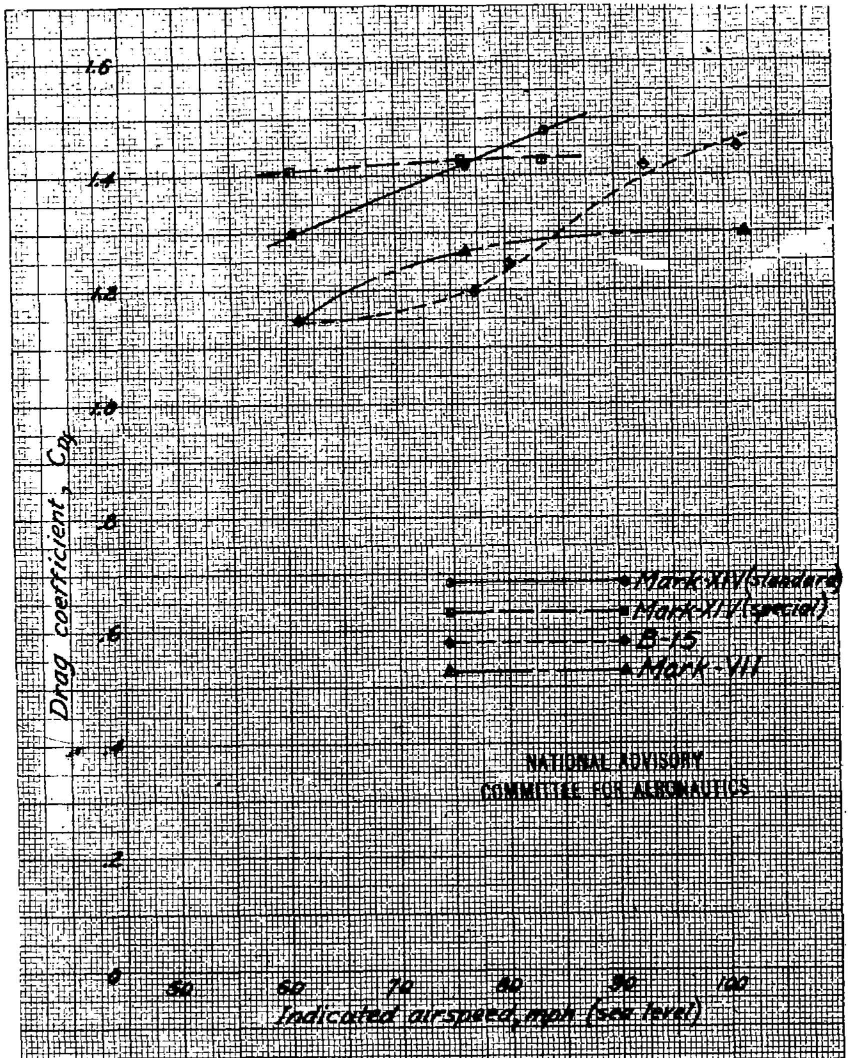

Figure 10. - Variation of drag coefficient with indicated airspeed for the full-size Navy tow targets.

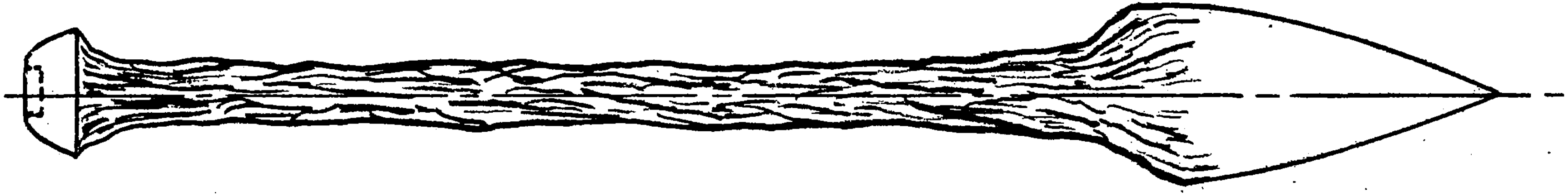

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Figure 11. - Shape of streamline target in flight in the NACA full-scale tunnel with fabric dry.

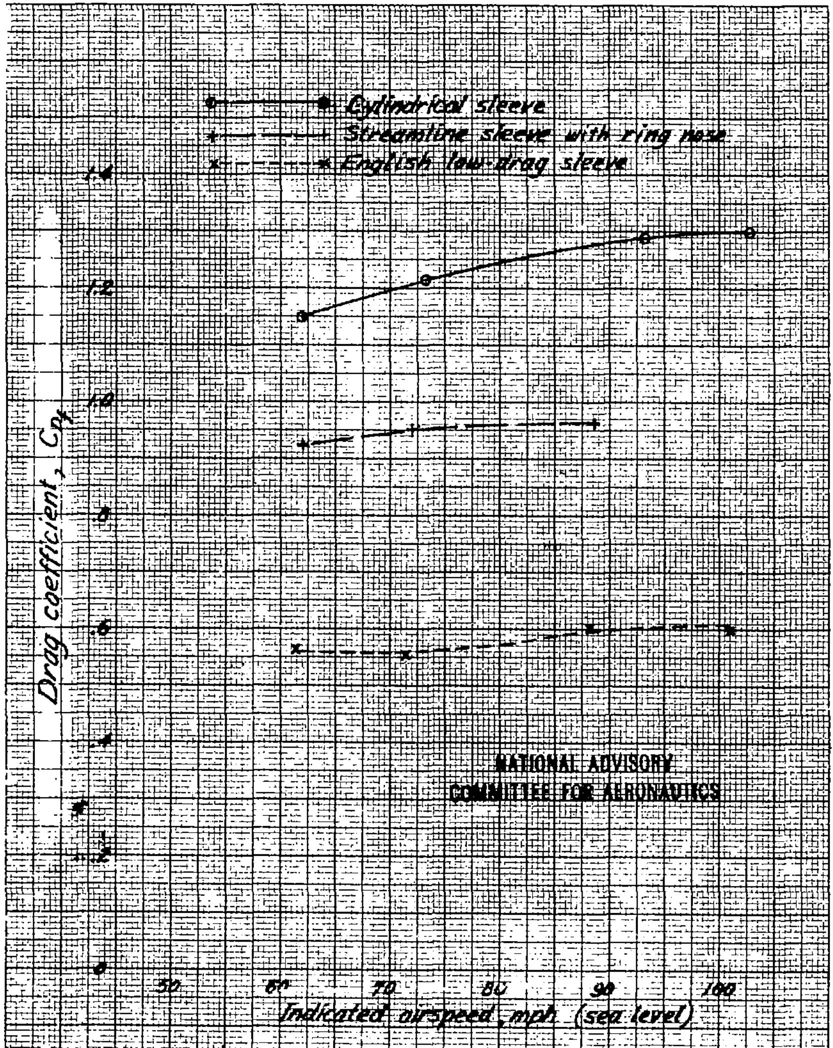

Figure 12. - Variation of drag coefficient with indicated airspeed for three basic tow-target shapes. Fabric dry.

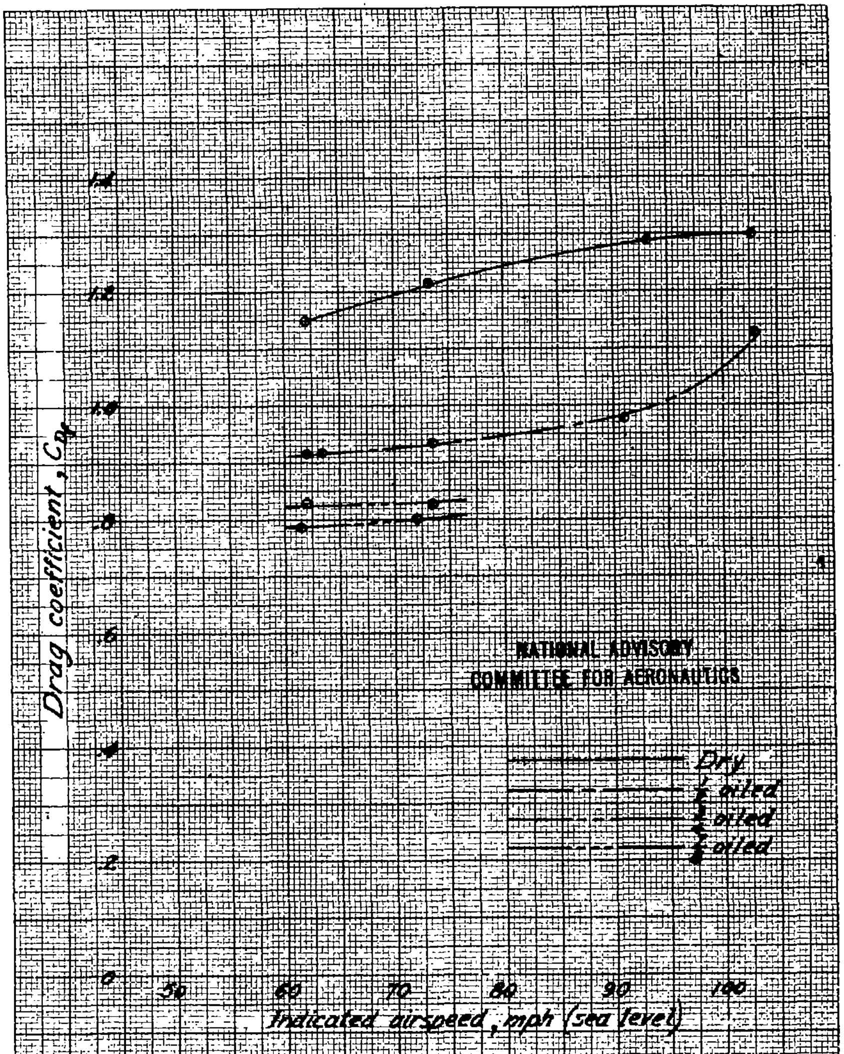

Figure 13. - Effect on the drag of decreasing the fabric porosity. One-third scale cylindrical model.

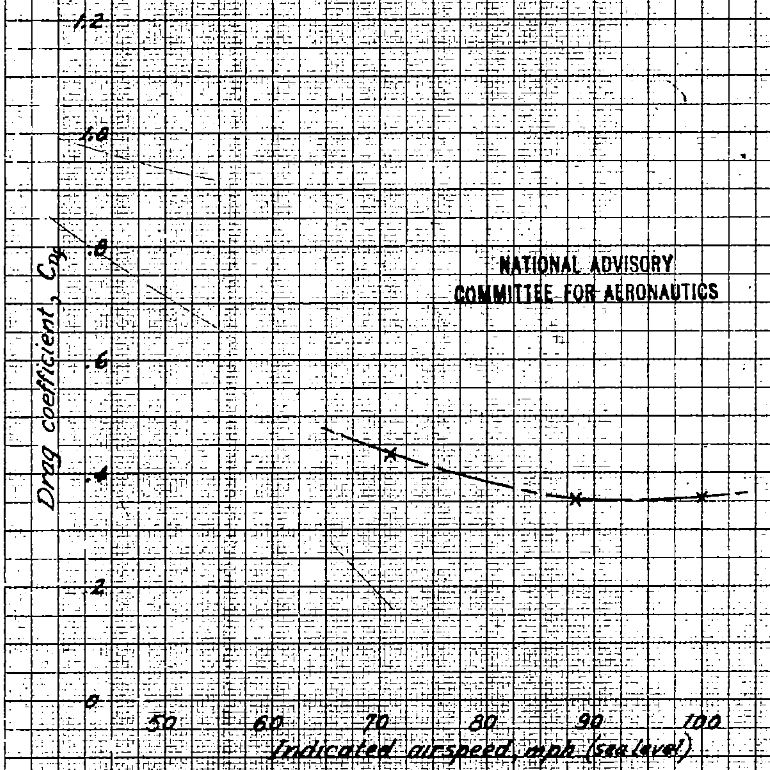

Figure 14. - Variation of drag coefficient with indicated airspeed for English low-drag sleeve. Taper section oiled.

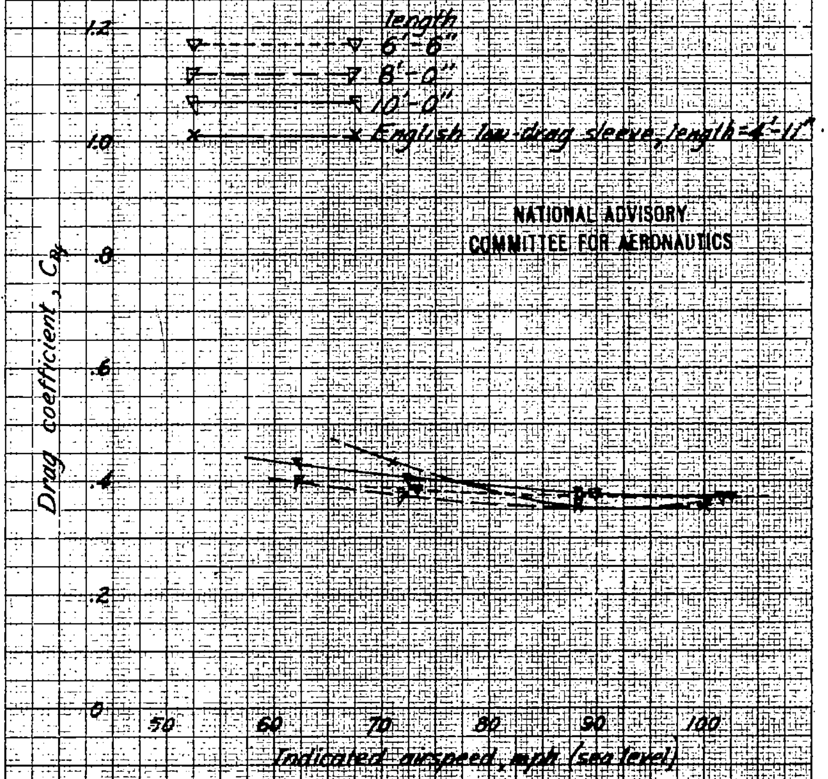

Figure 15. - Effect on the drag of increasing the length of the English-type sleeve. Straight taper; taper section wet.

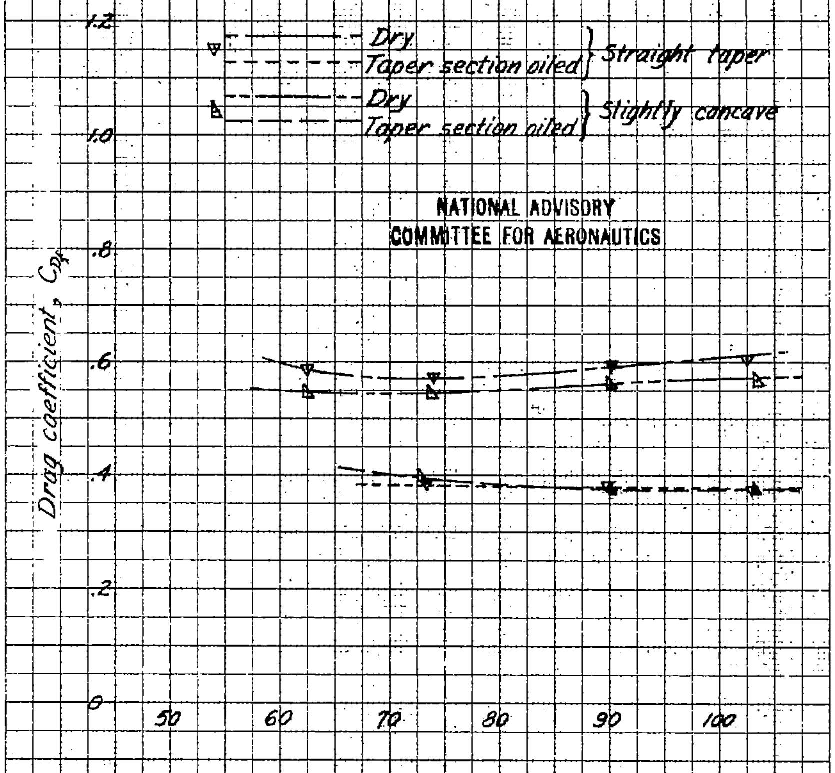

Figure 16. - Effect on the drag of changing the shape of the taper section of the English type target. Target length, $6\frac{1}{2}$ feet.

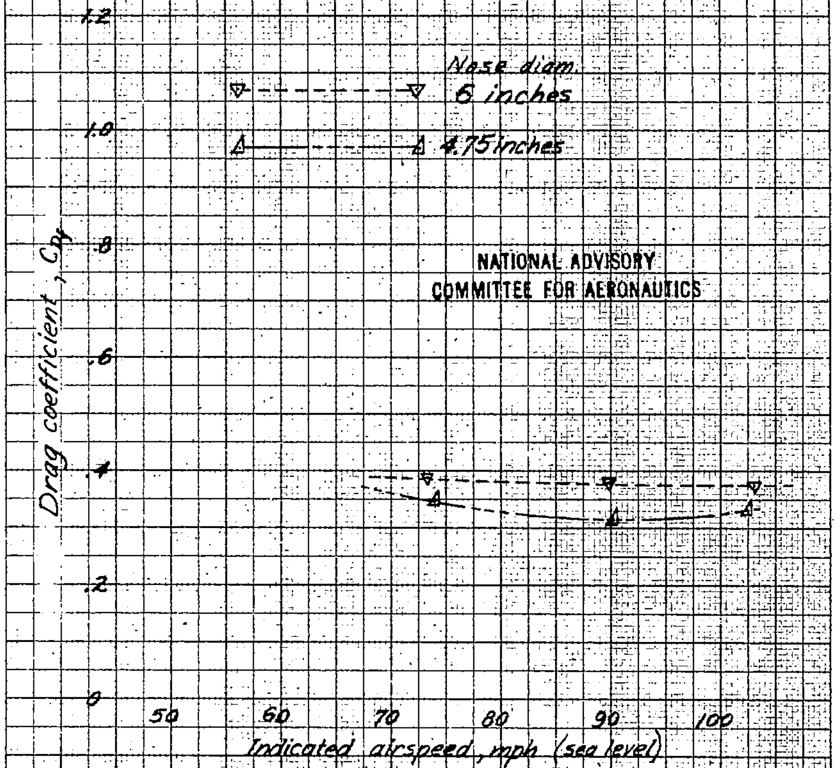

Figure 17. - Effect on the drag of reducing the nose diameter of the English type target. Target length, $6\frac{1}{2}$ feet; straight taper; taper section wet.

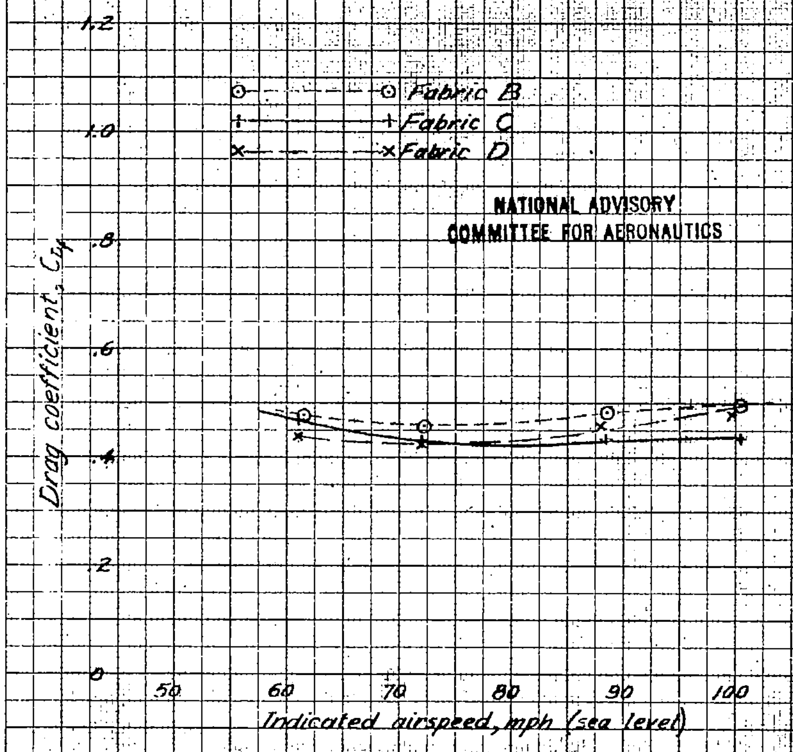

Figure 18. - Variation of drag coefficients with indicated airspeed for the English type sleeves constructed from different fabrics. Target length, 10 feet; straight taper; fabric dry.

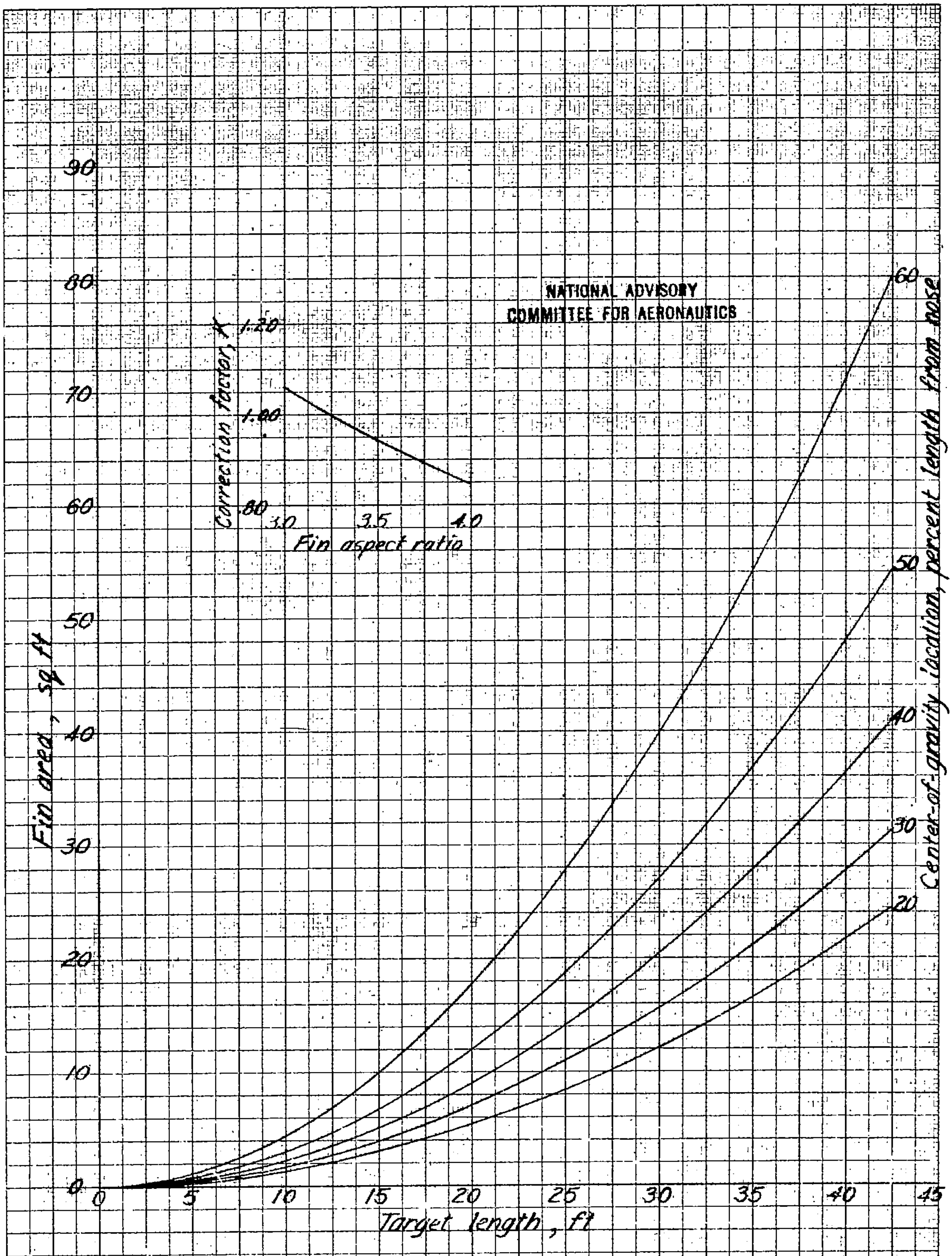

Figure 19. - Fin area required to obtain neutral stability for the rigid tow target with four fins.