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EFFECT OF SPANWISE BLOWING ON LEADING-EDGE VORTEX BURSTING OF A HIGHLY SWEPT ASPECT RATIO 1.18 DELTA WING

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16. Abstract

An investigation was conducted in the Langley 1/8-scale V/STOL model tunnel on a semispan delta wing with a leading-edge sweep of 74°, to determine the effectiveness of various locations of upper surface and reflection plane blowing on leading-edge vortex bursting. Constant area nozzles were located on the wing upper surface along a ray swept 79°, which was beneath the leading-edge vortex core. The bursting and reformation of the leading-edge vortex was viewed by injecting helium into the vortex core, and employing a Schlieren system.

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SUMMARY

An investigation was conducted in the Langley 1/8-scale V/STOL model tunnel on a semispan delta wing with a leading-edge sweep of 74°, to determine the effectiveness of various locations of upper surface and reflection plane blowing on leading-edge vortex bursting. Constant area nozzles were located on the wing upper surface along a ray swept 79°, which was beneath the leading-edge vortex core. The bursting and reformation of the leading-edge vortex was viewed by injecting helium into the vortex core, and employing a Schlieren system.

The results show that blowing from the nozzles in the wing upper surface located generally on a path under the leading-edge vortex, showed that as the distance from the apex to the nozzle location increases the flow rate required to maintain the leading-edge vortex past the wing trailing edge, at a given angle of attack, also increases. As the distance from the nozzle location to the apex increases, the distance between the jet and vortex edge becomes greater, which leads to the speculation that the jet of air enhances the vortex life by producing a more favorable pressure gradient at the edge of the vortex. Since the jet of air is at a relatively large distance from the edge of the vortex when the nozzles are located near the wing trailing edge blowing from those nozzles produced no noticeable effect on the leading-edge vortex bursting.

Blowing from the reflection plane parallel to the wing leading edge with the nozzle extended from the reflection plane and located closest to the apex, 25 percent of the root chord from the apex, produced the highest angle of attack with the least amount of mass flow rate without the leading-edge vortex bursting at the wing trailing edge.

INTRODUCTION

Employing fuselage blowing (blowing from the wing root) to enhance the leading edge vortex of a highly swept delta wing has been shown to be effective in increasing its maximum lift capability. Spanwise blowing enhances the leading-edge vortex and delays its bursting, at the trailing edge of the wing, to a higher angle of attack (reference 1). Considering this, it becomes desirable to examine the potential benefits for aircraft technology offered by upper surface blowing along the leading-edge vortex axis rather than at the wing root as a means of achieving high lift. As part of a research program on spanwise blowing the Langley Research Center recently conducted a qualitative study to determine the effect of blowing location on the enhancement of leading-edge vortex life. This study is being conducted with a semispan delta wing having a leading-edge sweep angle of 74° (aspect ratio 1.18), and ten different nozzles location on the wing upper surface and the reflection plane. The bursting and reformation of the leading-edge vortex was viewed by injecting helium into the vortex core through the nozzle located nearest the wing apex. The vortex core could then be viewed by employing a Schlieren system. The tests were conducted in the Langley 1/8 - scale V/STOL model tunnel at a dynamic pressure of 1.56 lbs/ft^2 at angles of attack between 13° and 42°.

SYMBOLS

b	wing span
c	root chord
L	distance of nozzle from apex
q	dynamic pressure, lbs/ft^2

S	semi-span wing area, in^2
α	angle of attack, deg.
α'	angle at which leading-edge vortex bursts at trailing edge, deg.
Λ	leading-edge sweep angle, deg.

MODEL DESCRIPTION

A drawing of the model studied is presented in figure 1. Figures 2(a) and 2(b) show the semi-span model mounted on the side wall of the tunnel. The wing is an aspect ratio 1.18, semi-span delta wing ($\Lambda = 74^{\circ}$) with six 1/4-inch constant area nozzles placed flush to the wing upper surface (see figure 1, section A-A) along a ray, which was swept 79°. The location of the nozzles was chosen such that the nozzles lie along the path of the vortex. The path of the vortex was determined from data presented in reference 2. The chordwise positions of the nozzles are given in figure 1. The blowing was directed along this 79° swept ray on the wing upper surface. Accompanying these six nozzles are two additional wing surface nozzles (located at L/c = 0.17 and 0.25) of the same specifications with the exception that their direction of blowing is along a ray which is swept 78°. The sharp leading edge and narrowness of the wing in the apex region prevented the placement of these nozzles along the 79° ray.

In addition to blowing from nozzles located along the path of the vortex, the present study included blowing from four nozzles located in the model reflection plane. Two of the nozzles were located at L/c = 0.25 and two at L/c = 0.34. All four nozzles were constant area, directed parallel to the wing leading edge and located approximately 7/16 of an inch above the wing upper surface.

One nozzle at each of the locations (L/c = .25 and .34) was mounted flush with the reflection plane. These nozzles were 1/4-inch in diameter. The second nozzle at each locations (L/c = .25 and .34) extended approximately 3/4 of an inch out of the reflection plane (see figure 1 (b)) and had a 3/16-inch diameter.

The model was 11/32 inches thick, flat plate with a sharp leading and trailing edge, and had a root chord of 15 inches. The wing was mounted on a circular disk that was fitted into the reflection plane for simplified angle-of-attack manipulation.

APPARATUS TEST

The present investigation was conducted in the Langley 1/8-scale V/STOL model tunnel. The bursting of the leading-edge vortex at the trailing edge of the wing was determined by observing the vortex bursting bubble. This bursting bubble was viewed by means of a Schlieren system and the addition of helium into the vortex core. Helium was introduced into the vortex core by injecting the helium into the flow field at the nozzle located at $L/c = 0.17$. Since helium is a low density gas, it migrated to the low pressure region of the vortex core, thus enabling the core to be observed using the Schlieren system. The complete setup is shown in figure 2(a).

High pressure air was also injected into the flow field at the locations shown in figure 1 (except the location at $L/c = 0.17$ through which helium was injected as previously stated). The mass flow rates of the helium and air were obtained by means of flow meters shown in figure 2(a).

Tests were made at a dynamic pressure of 1.56 lbs/ft^2 at angles of attack of approximately 13° to 42°. The free-stream dynamic pressure was measured using the static-pitot pressure tube shown in figure 2(b). The model tests were conducted with boundary-layer transition free. The blockage and jet-boundary corrections were believed to be negligible and therefore were not applied to the data.

DISCUSSION OF RESULTS

As mentioned earlier, the leading-edge vortex of the aspect ratio 1.18 delta wing was viewed by injecting helium into the vortex core and viewing the helium filled core with a Schlieren system. A sketch of the leading-edge vortex and the leading-edge vortex bursting bubble as viewed is presented in figure 3.

A study was made to determine if an adequate helium blowing rate from a flow visualization standpoint could be used without appreciably affecting the vortex characteristics. The helium was injected into the vortex core through the nozzle located nearest the delta wing apex (L/c = .17 station). Blowing helium from that location had an effect on the angle of attack at which the leading-edge vortex burst (see figure 4). Vortex breakdown was delayed up to about 42° for the higher blowing rates. With a helium flow rate of 1.4 cfm, the vortex became visible at approximately 13° angle of attack, and burst in the vicinity of the trailing edge at an angle of attack of approximately 33.7°. The experimental data of reference 2 shows that the leading-edge vortex burst in the vicinity of the wing trailing edge with no blowing at an angle of attack between 30° and 35°. From the data of figure 4 it is indicated that the lower blowing rates do not appear to alter the vortex break down characteristics. For this reason the lower value of helium flow rate (1.4 cfm) was selected to provide flow visualization for the entire test program.

Since the data was qualitative it was felt that three separate runs at each nozzle location would be required to adequately define the trends. Figure 5 presents the data obtained from the three separate runs for the nozzle locations L/c = 0.25, 0.34, 0.45, 0.57. As can be seen, increasing the flow rate increases the angle of attack that could be reached before the leading-edge vortex burst at the trailing edge. At the highest flow rates at each station the high pressure jet of air appeared to mix with the helium jet thus making flow visualization impossible. Increasing the helium flow rate when the air jet flow rate was at the maximum amount shown for each nozzle location in figure 5 would have made flow visualization possible, but since the helium did affect the leading-edge vortex bursting, the flow rate was not increased and the test was terminated.

The data in figure 5(c) (blowing from L/c = .45) would seem to indicate that increasing the blowing rate a small amount would yield much higher attainable angles of attack without leading-edge vortex bursting. The reason for the different shaped curve in figure 5(c) as compared to figures 5(a), 5(b) and 5(d) is not understood at this time.

The leading-edge vortex bursting for blowing from the L/c = 0.57 station (see figure 5(d)) becomes very sensitive to angle of attack, flow rate, and disturbances in the tunnel flow, thus making repeatability very difficult.

Blowing from the location at L/c = 0.70, 0.80, and 0.91 produces no visible effect on the angle of attack at which the leading-edge vortex burst.

Figure 6 shows the averaged data from the three runs of each nozzle location of which data were obtained. As the distance from the apex to the nozzle location increases the flow rate required to maintain the leading-edge vortex past the trailing edge of the wing at a given angle of attack also increases. In general, the distance between the jet of air coming from each nozzle and the edge of the vortex becomes greater as the L/c increases. This leads to speculation that the jet of air produces a favorable pressure gradient of the edge of the vortex (ref. 3). This also would explain why blowing from the nozzles located at L/c = 0.70, 0.80, 0.91 had no effect on vortex reformation; the jet of air was at a greater distance from the vortex edge then that required to reform it.

A study was also made on the concept of blowing from the reflection plane, parallel to the leading edge at the L/c stations of 0.25 and 0.34. The results are presented in figure 7. Since the data for the L/c = 0.25 station, nozzle flush to the reflection plane, and nozzles at the L/c = 0.34 station were repeatable, only one run was made for the extended nozzle of the L/c = 0.25 station. (See figure 7(b).) Figure 8 presents averaged data from runs at both nozzle locations in the reflection plane. It is noted that the extended nozzle in both locations produces a higher angle of attack with a lesser amount of air flow than that for the flush nozzle configurations. It is believed that this is because the nozzle extension places the jet closer to the vortex edge. The data in figure 9 indicates that less mass flow rate of air is required from the nozzle located at L/c = 0.25, than for the nozzle located at L/c = 0.34, to delay leading-edge vortex bursting at the same angle of attack. Again the nozzle nearer the apex produces a more favorable curve.

Figure 10 presents a comparison between reflection plane blowing and blowing from the wing surface beneath the vortex, core. It appears that the nozzle located at the L/c = 0.25 station in the reflection plane, extended configuration, proves to be the most efficient location studied. It produced a higher angle of attack (40°) with a lesser amount of air flow (less than 2.5 cfm) than any other location. At the L/c = 0.34 station, upper surface blowing is shown to be more effective than reflection plane blowing.

CONCLUSIONS

A study was conducted on a semispan 74° swept (aspect ratio 1.18) delta wing to determine the effect of spanwise blowing on the enhancement of the leading-edge vortex life. As a result of this qualitative study, some of the major conclusions that can be drawn are:

1. Blowing from the nozzles in the wing upper surface located generally on a path under the leading-edge vortex, showed that as the distance from the apex to the nozzle location increases the flow rate required to maintain the leading-edge vortex past the wing trailing edge, at a given angle of attack, also increases. As the distance from the nozzle location to the apex increases, the distance between the jet and vortex edge becomes greater, which leads to the speculation that the jet of air enhances the vortex life by producing a more favorable pressure gradient at the edge of the vortex.

2. Since the jet of air is at a relatively large distance from the edge of the vortex when the nozzles are located near the wing trailing edge, blowing from those nozzles produced no noticeable effect on the leading-edge vortex bursting.

3. Blowing from the reflection plane parallel to the wing leading edge with the nozzle extended from the reflection plane and located closest to the apex, 25 percent of the root chord from the apex, produced the highest angle of attack with the least amount of mass flow rate without the leading-edge vortex bursting at the wing trailing edge.

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3. Bossel, H. H.: Vortex Equations: Singularities, Numerical Solution, and Axisymmetric Vortex Breakdown. NASA CR-2090, July 1972.

S = 66.56 IN.^{2}
b/2 = 8.875
C = 15 IN.

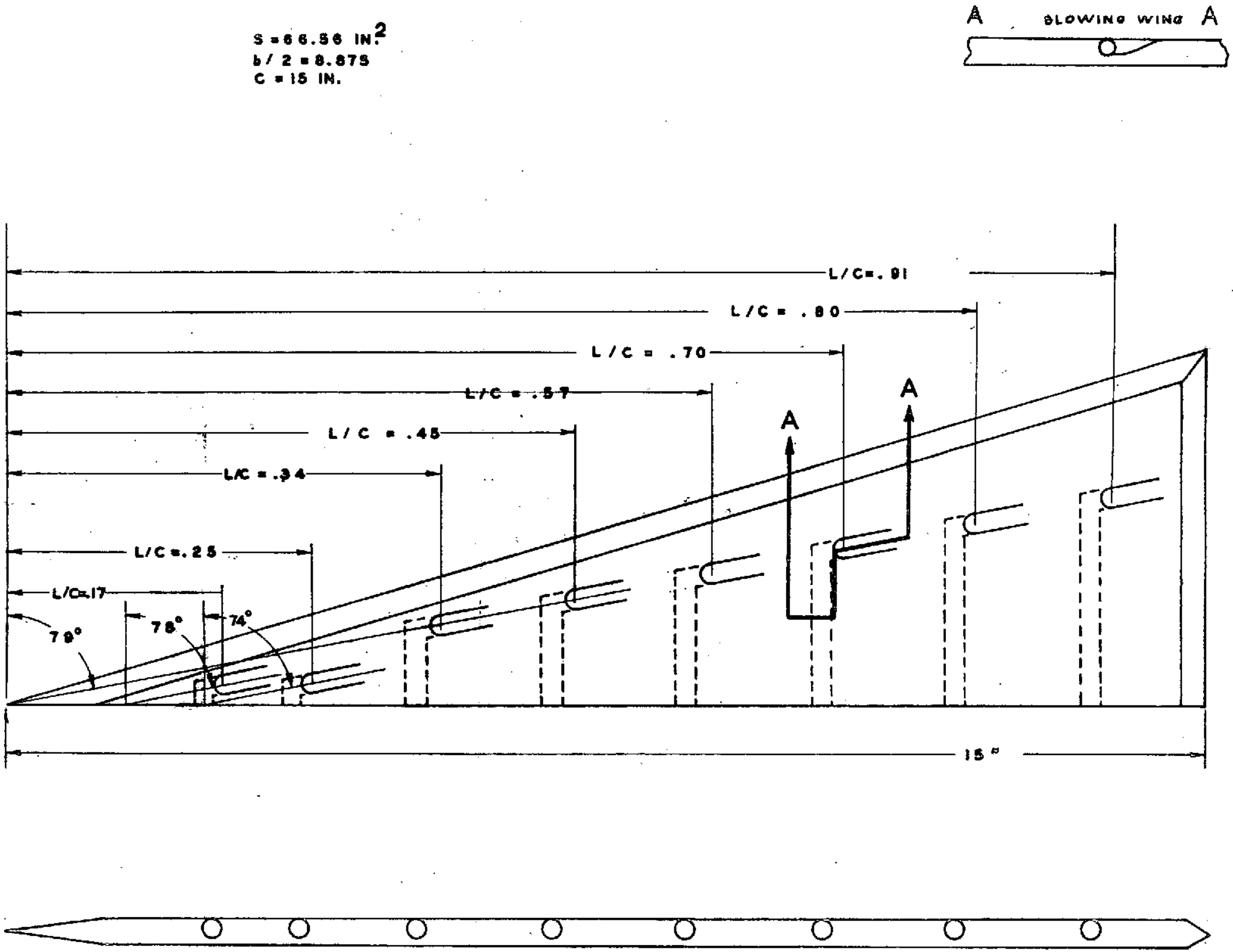
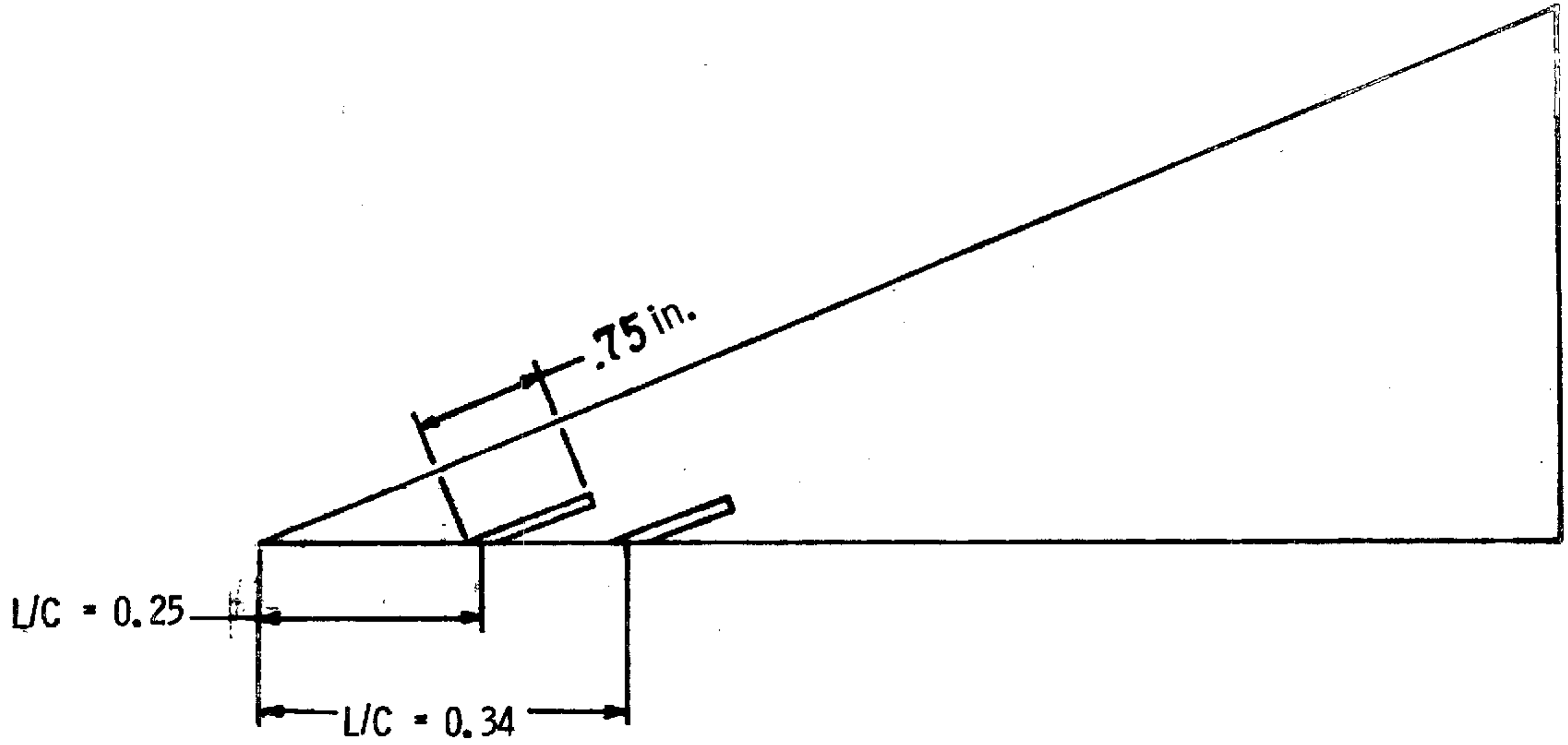
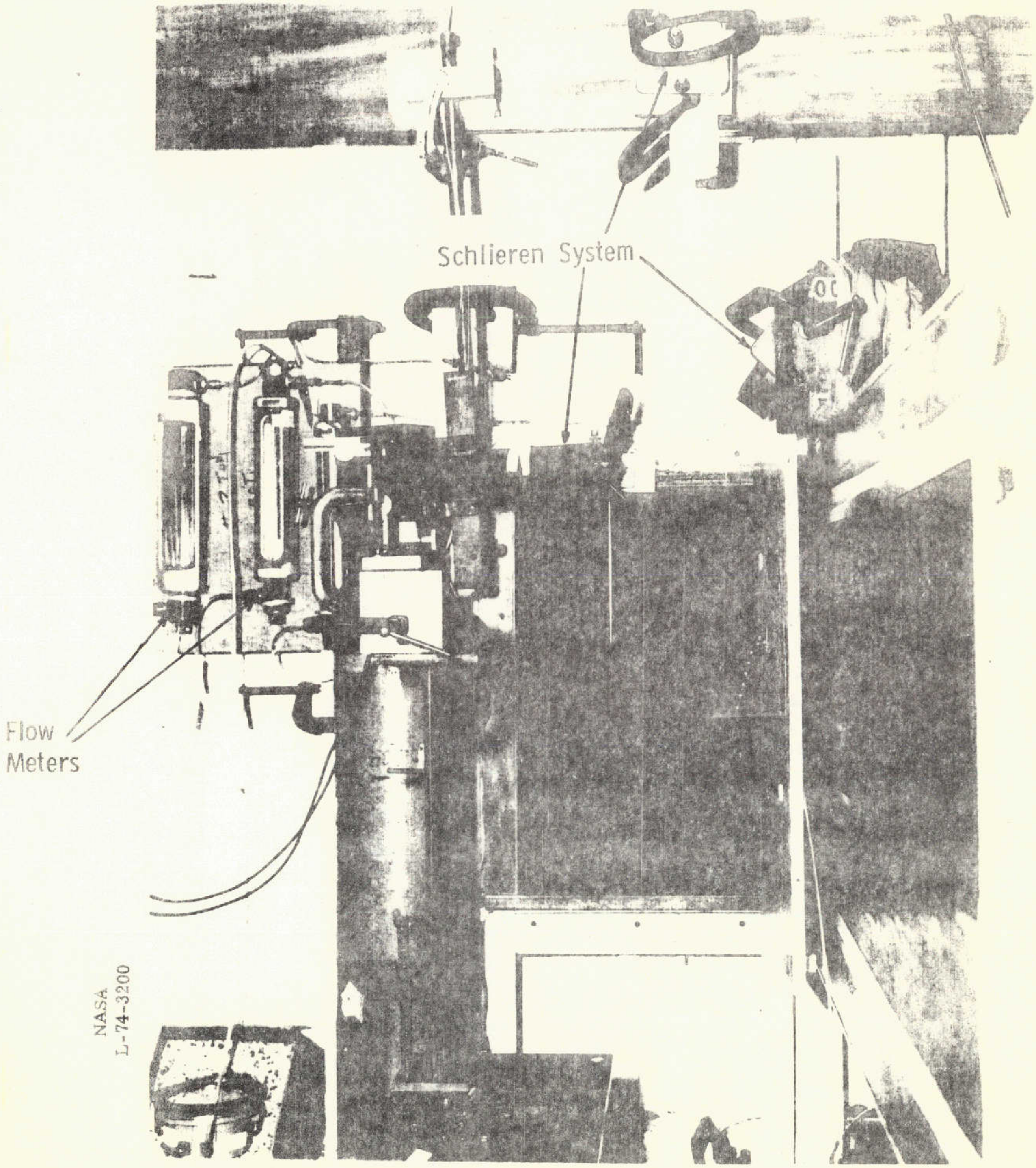


Figure 1.- Model drawing.



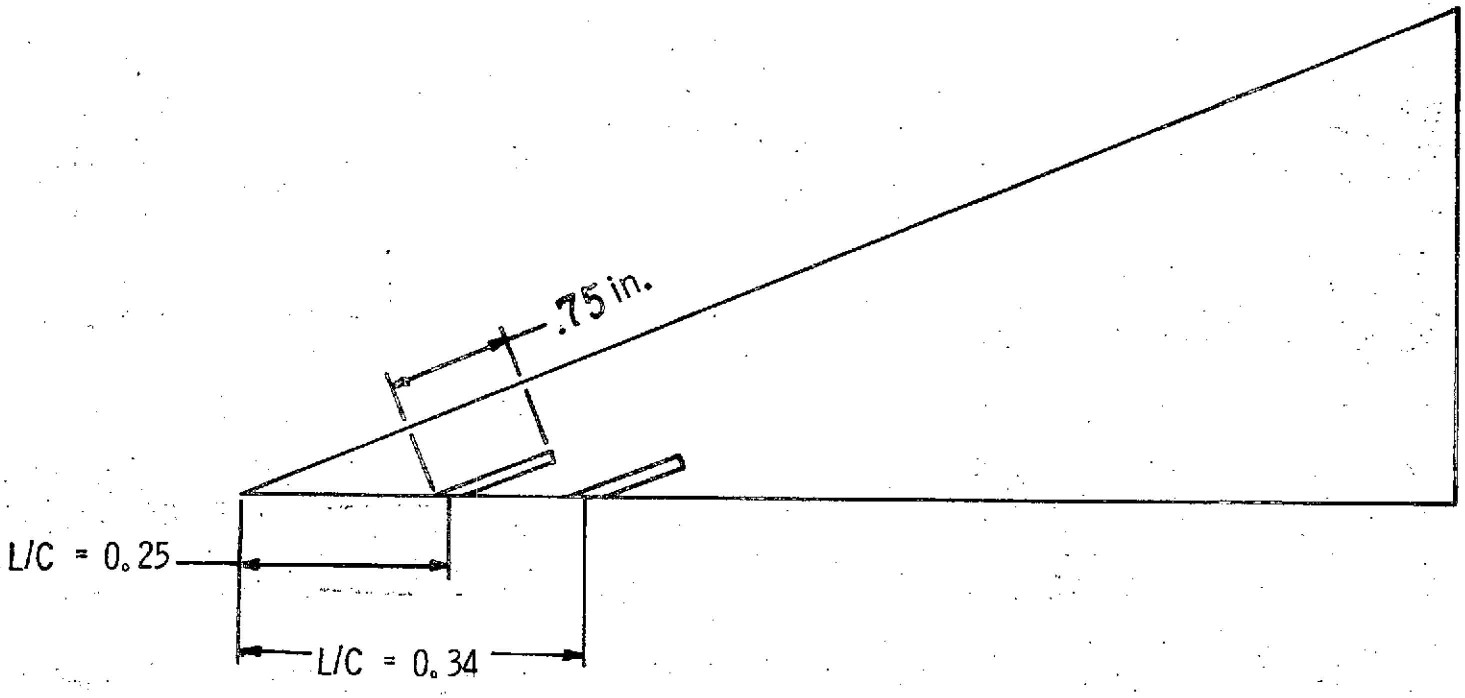
(b) Extended nozzles on reflection plane.

Figure 1.- Continued.



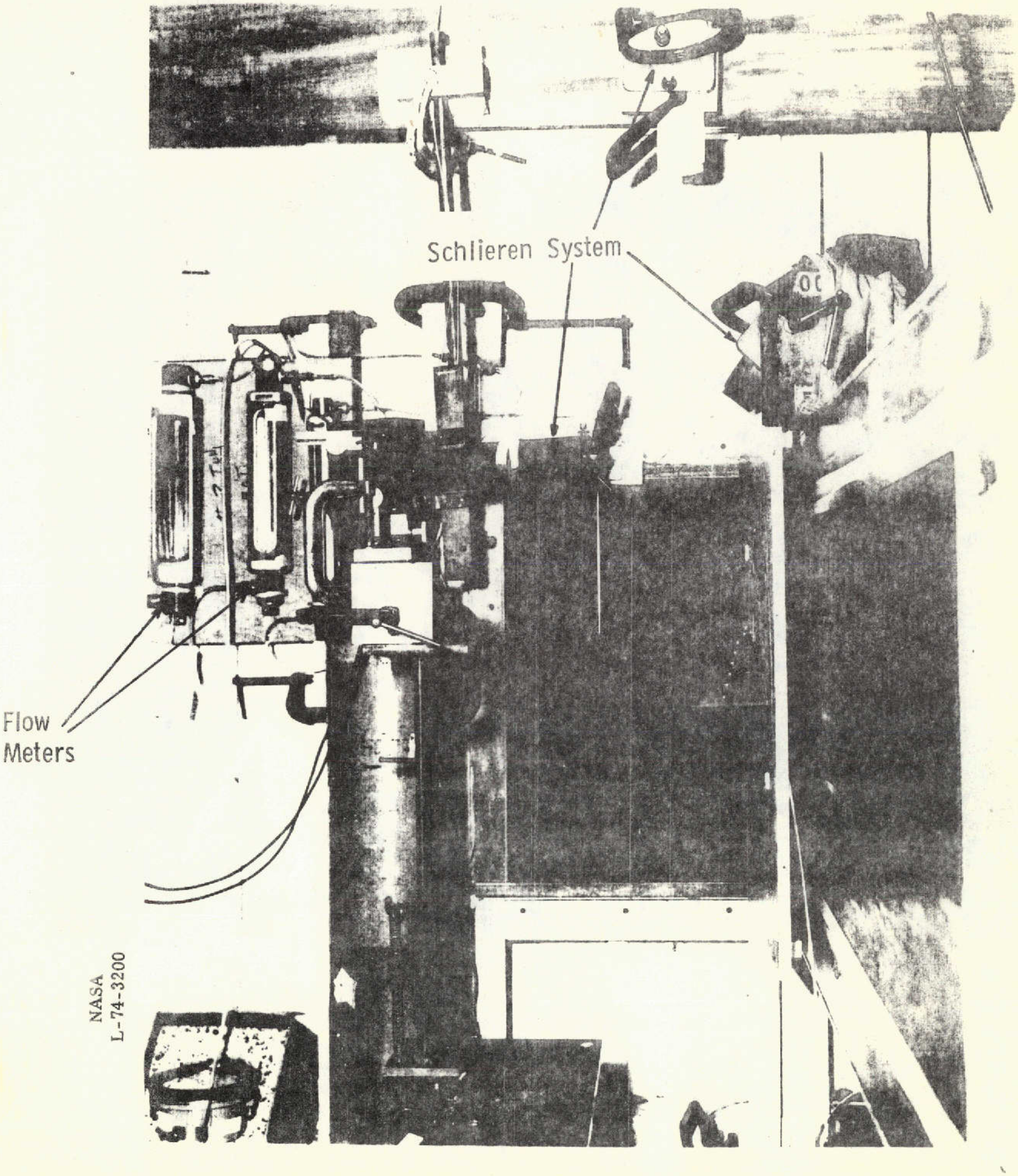
(a) View from rear of model

Figure 2.- Photographs of model and test section.



(b) Extended nozzles on reflection plane.

Figure 1.- Continued.



(a) View from rear of model

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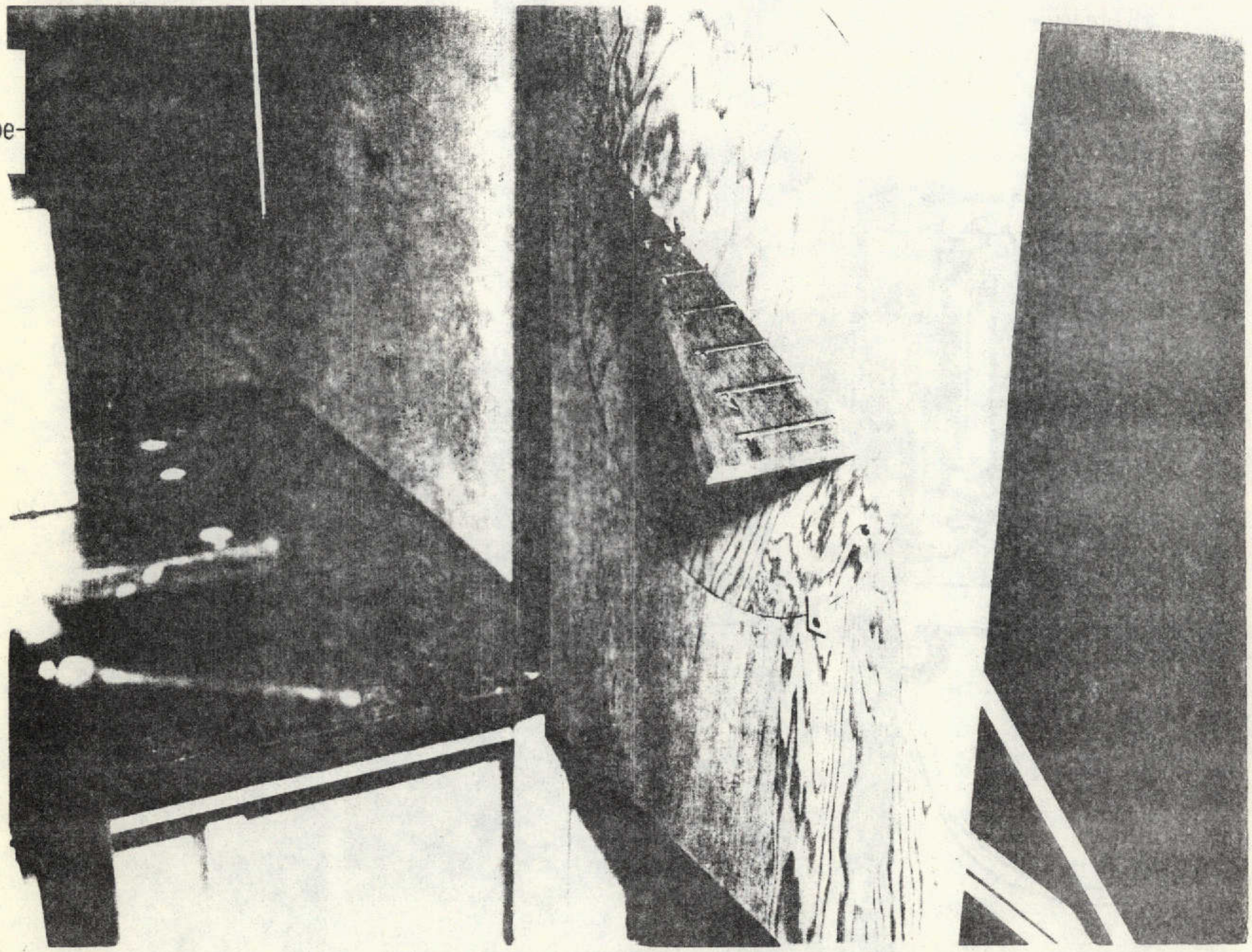


(b) Wing mounted on reflection plane

Figure 2.- Continued.

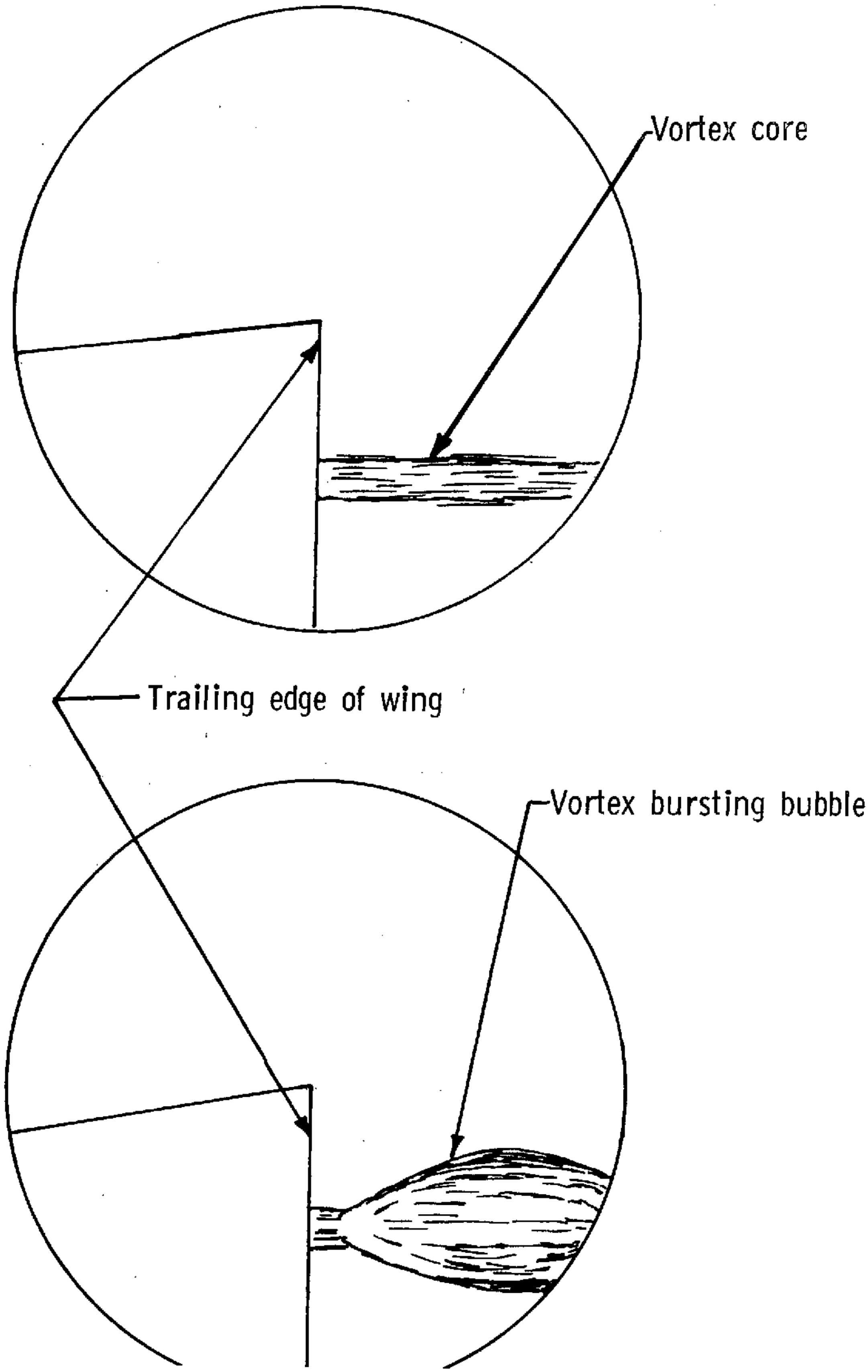


Figure 3.— Sketch of vortex and vortex bursting bubble as viewed by Schlieren.

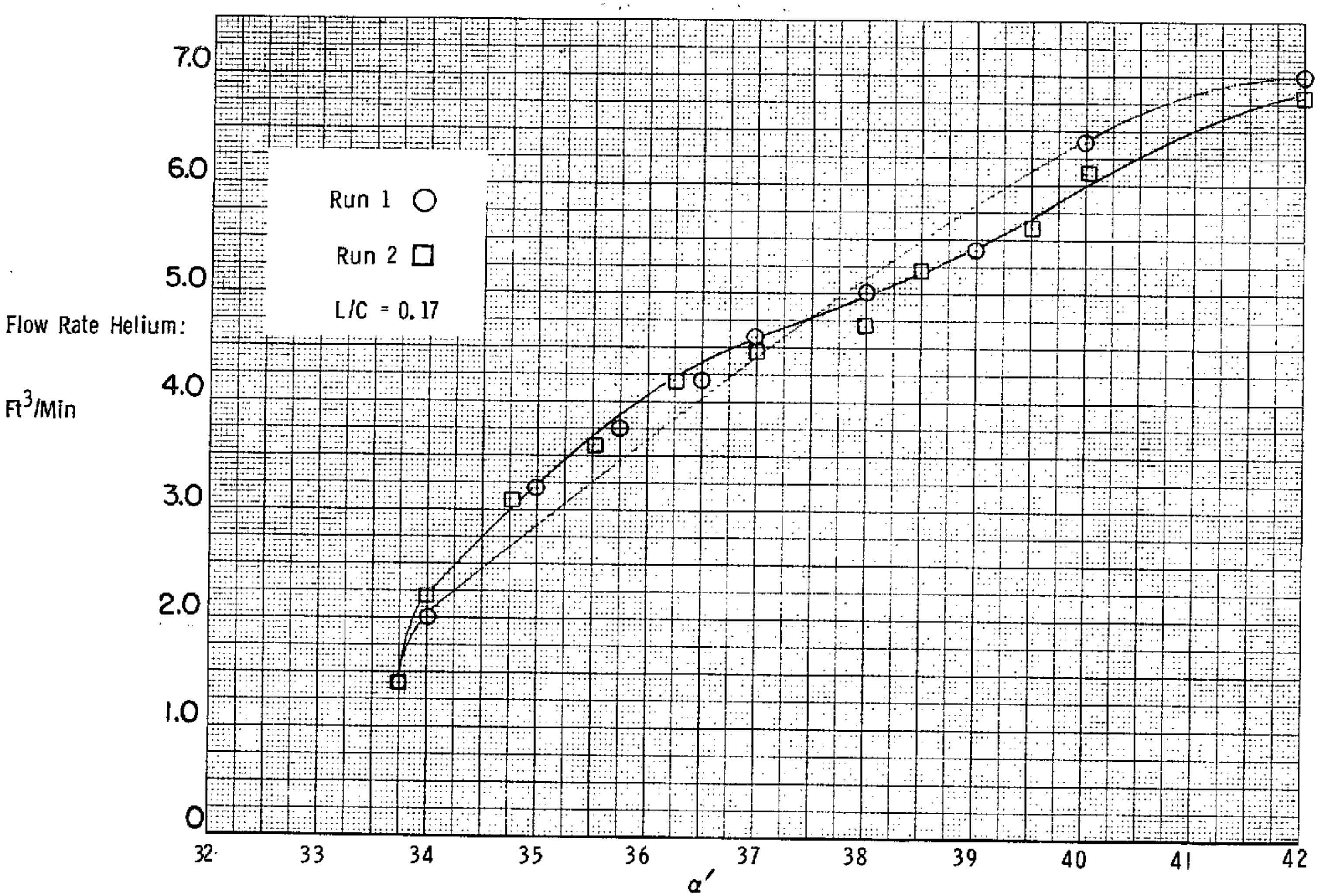


Figure 4.- Helium flow rate versus angle at which leading-edge vortex burst.

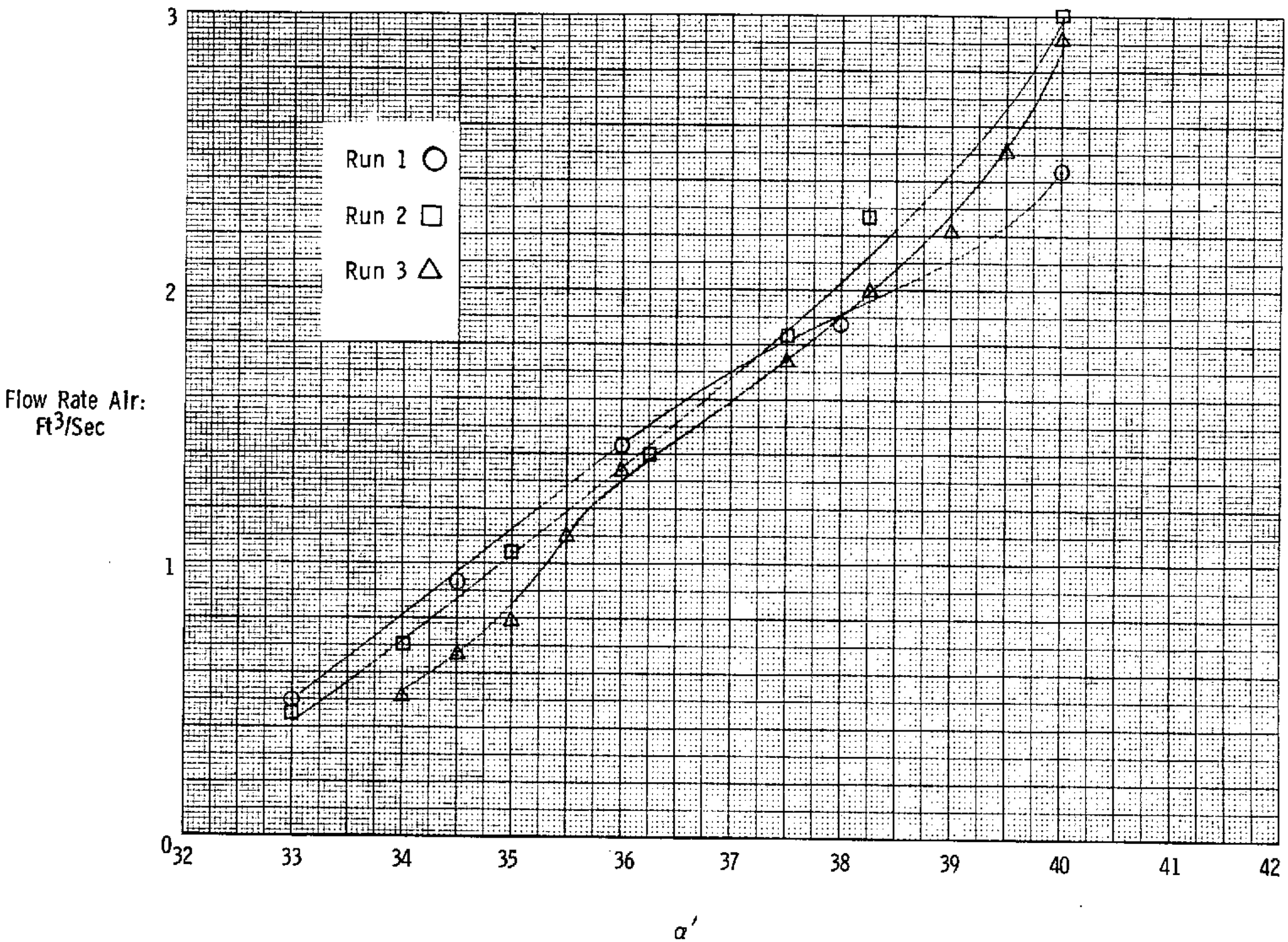
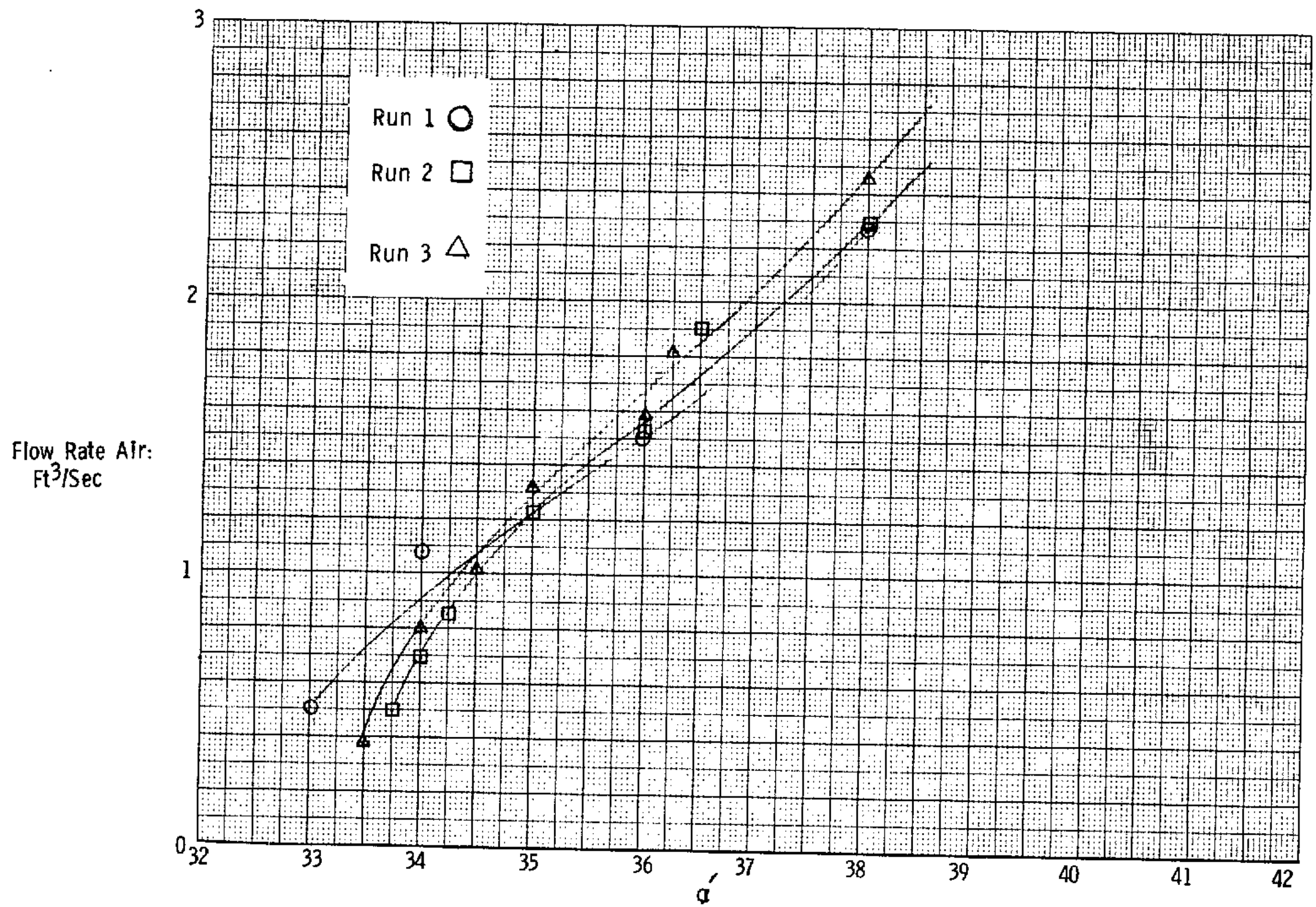
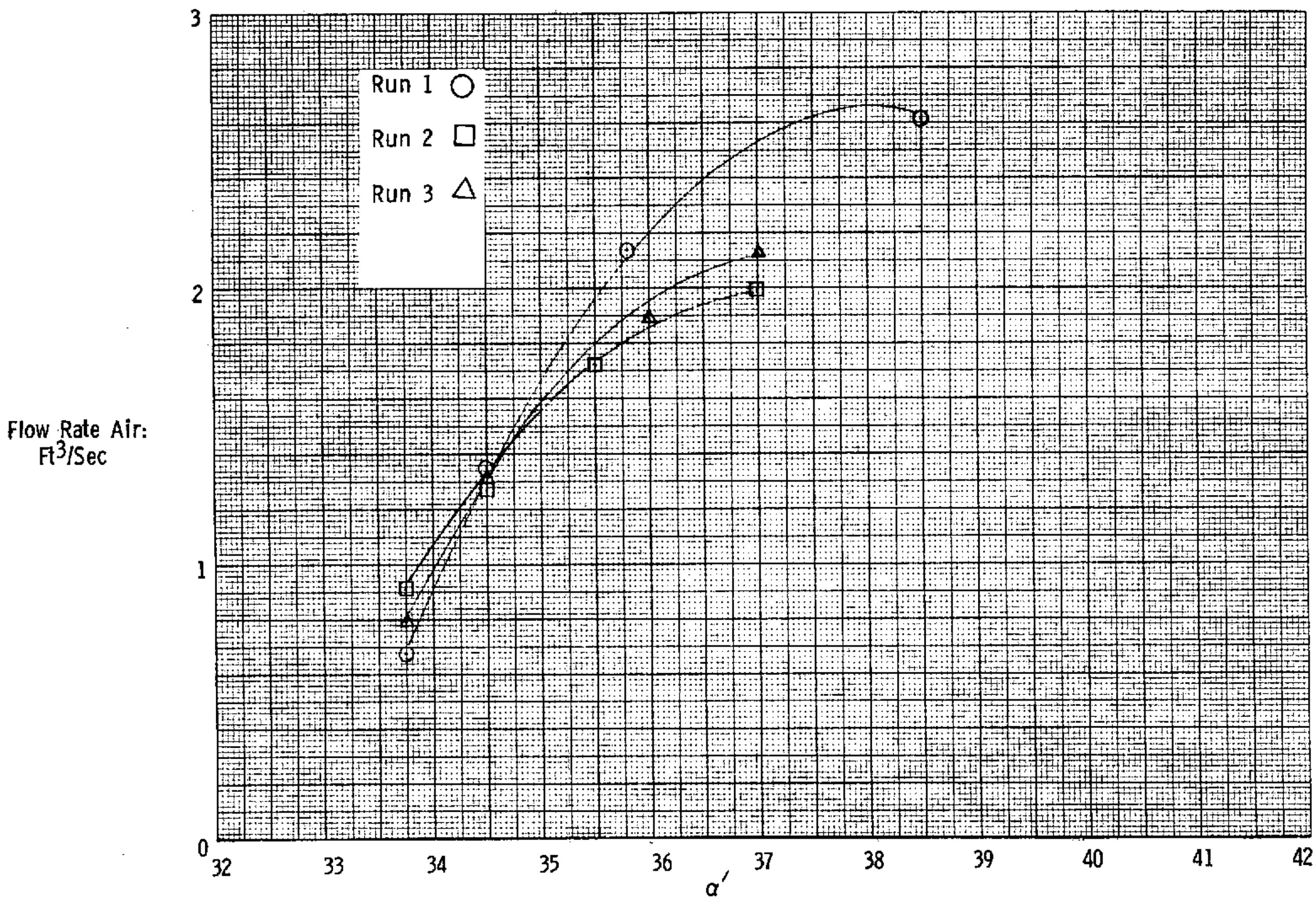


Figure 5 .- Amount of blowing needed to prevent bursting of leading-edge vortex at trailing edge, $L/C = 0.25$.



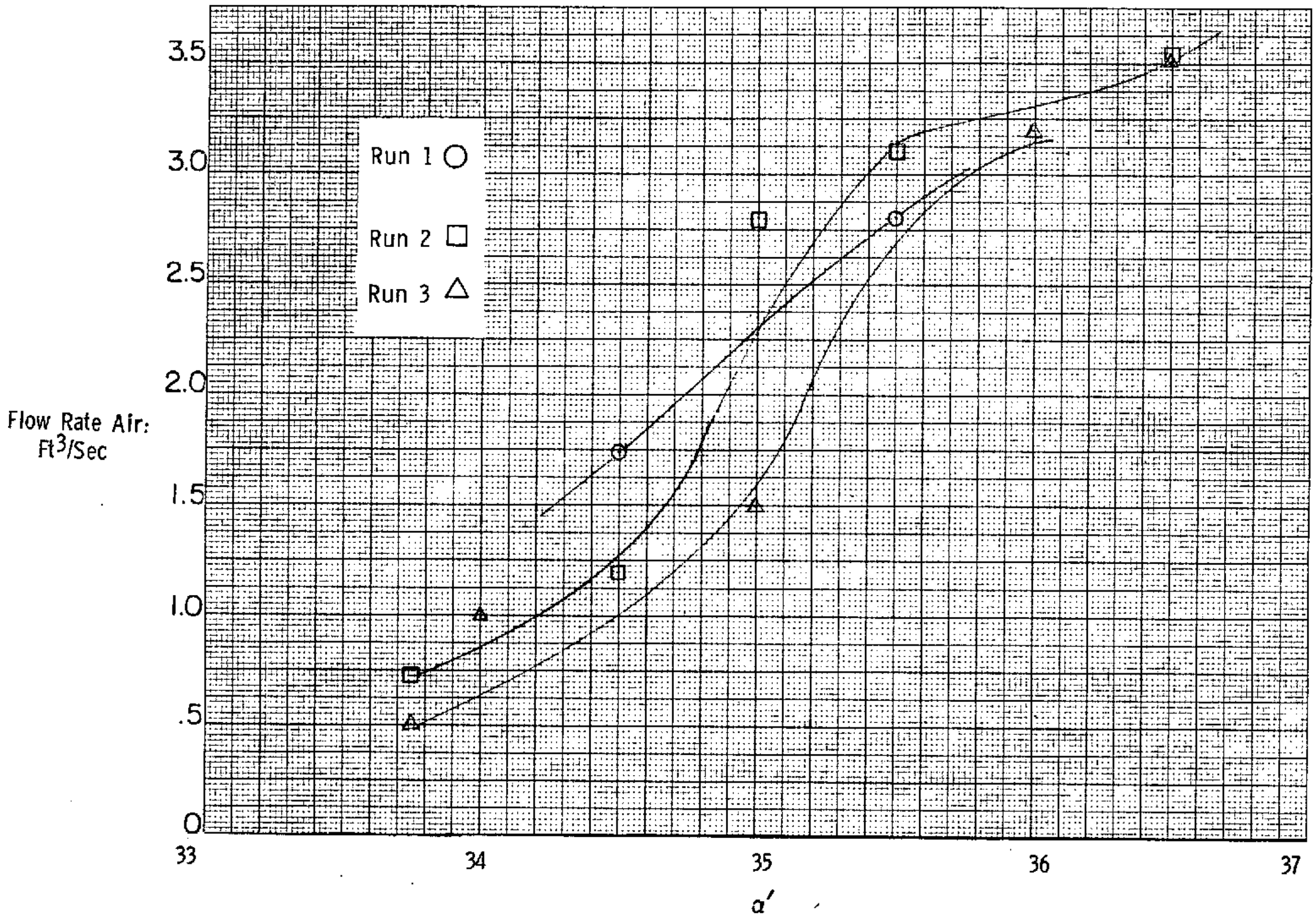
(b) L/C = 0.34

Figure 5 - Continued.



(c) L/C = 0.45

Figure 5.- Continued.



(d) L/C = 0.57

Figure 5. - Concluded.

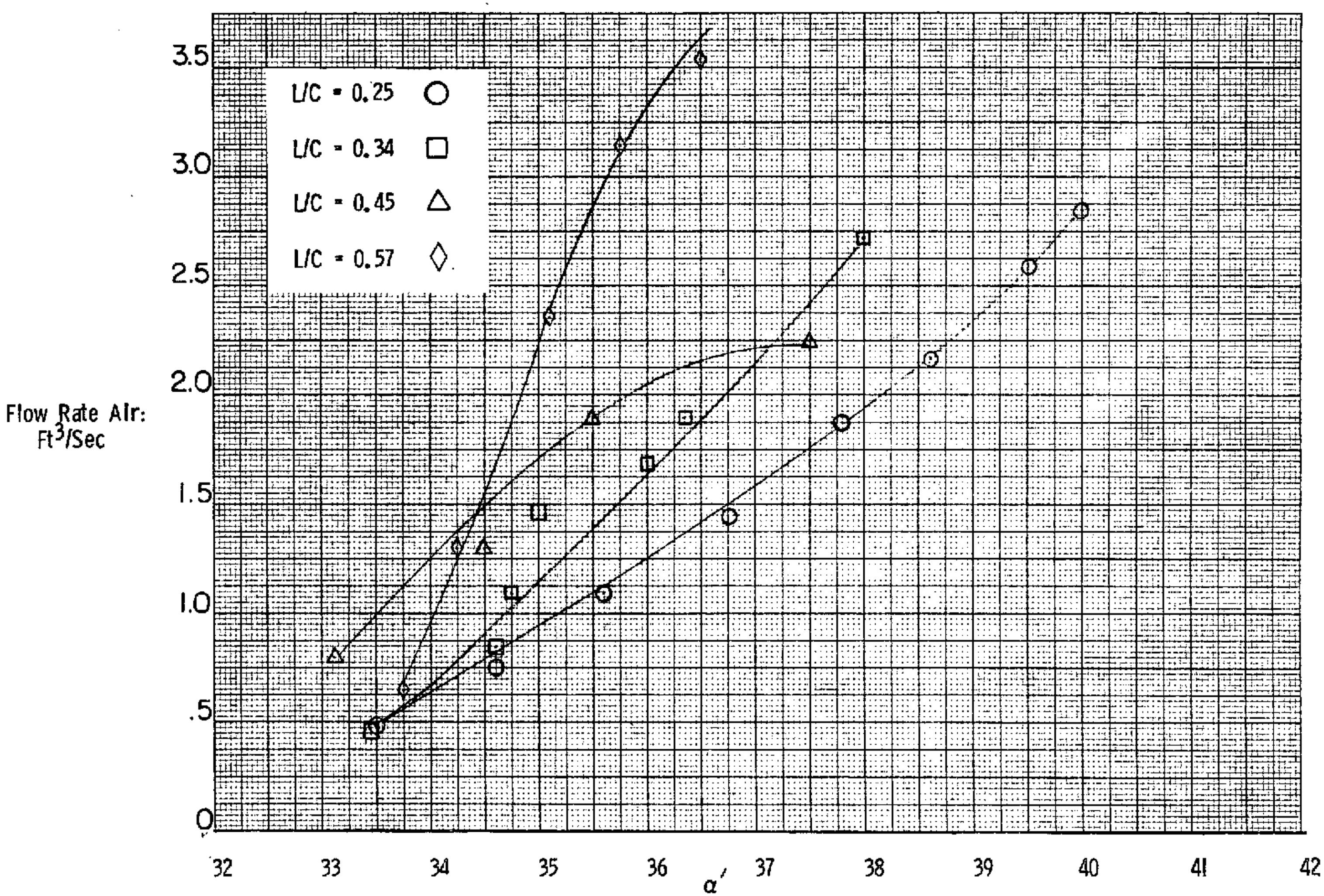


Figure 6.- Average of three separate runs for each nozzle location.

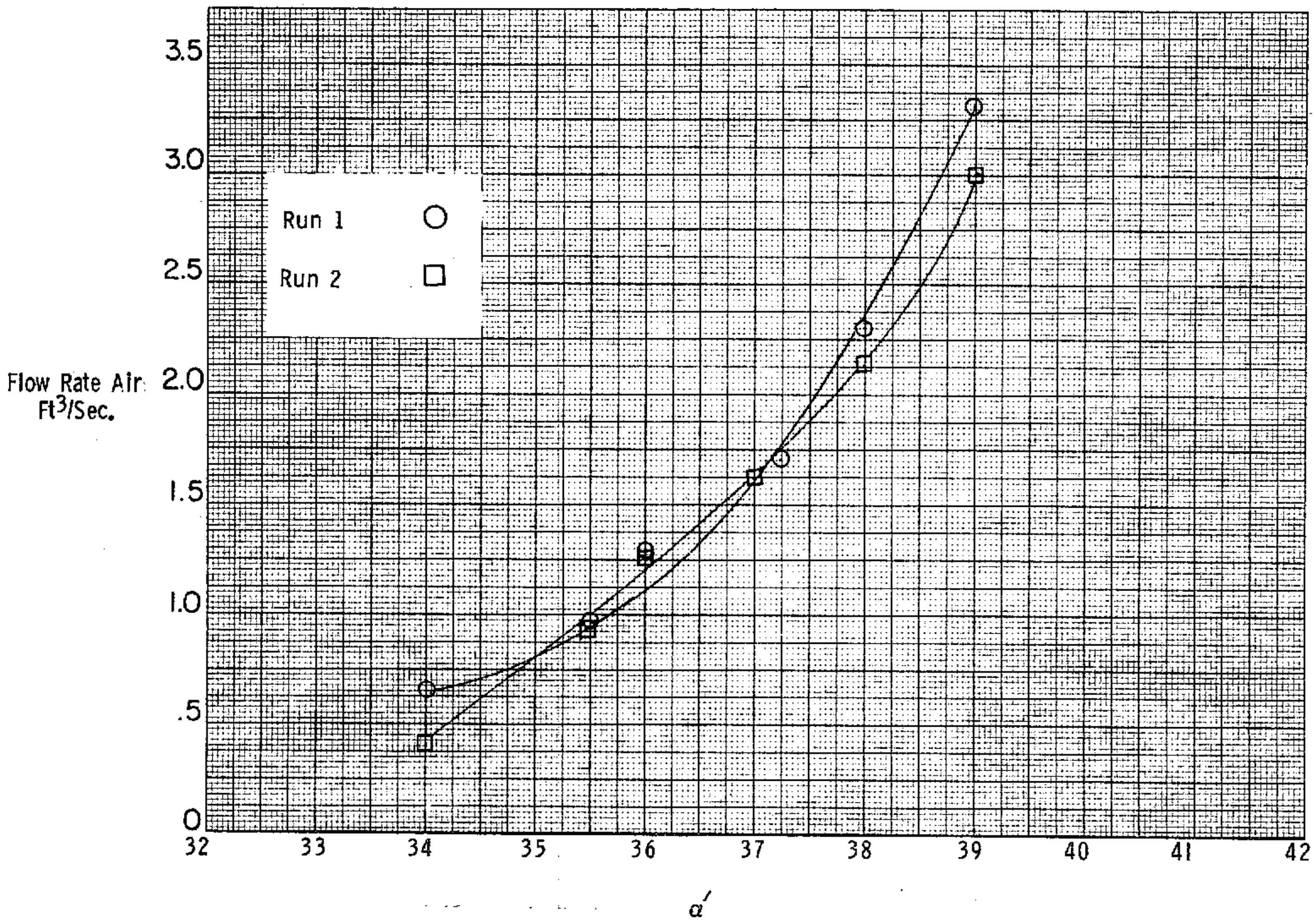
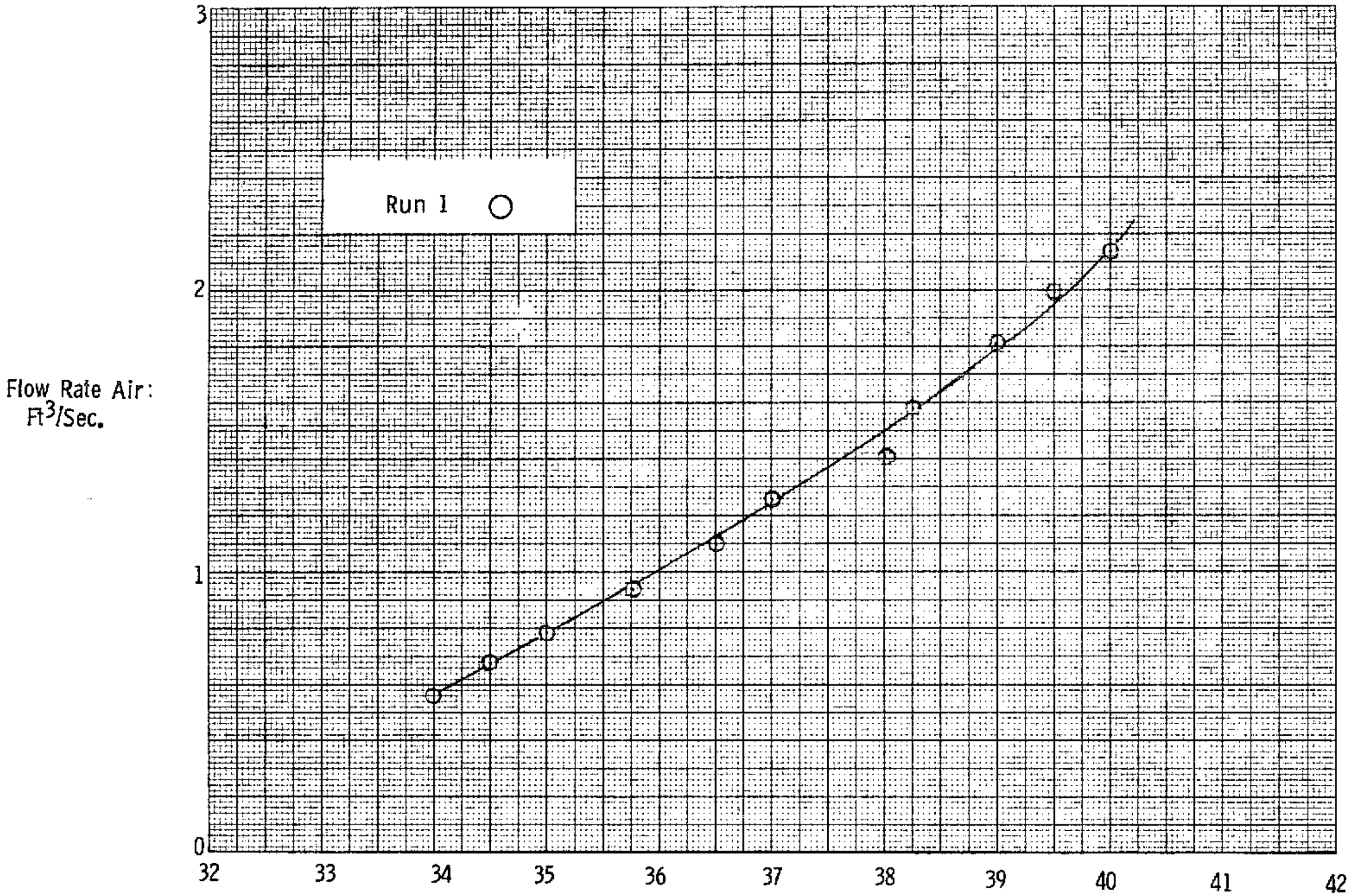
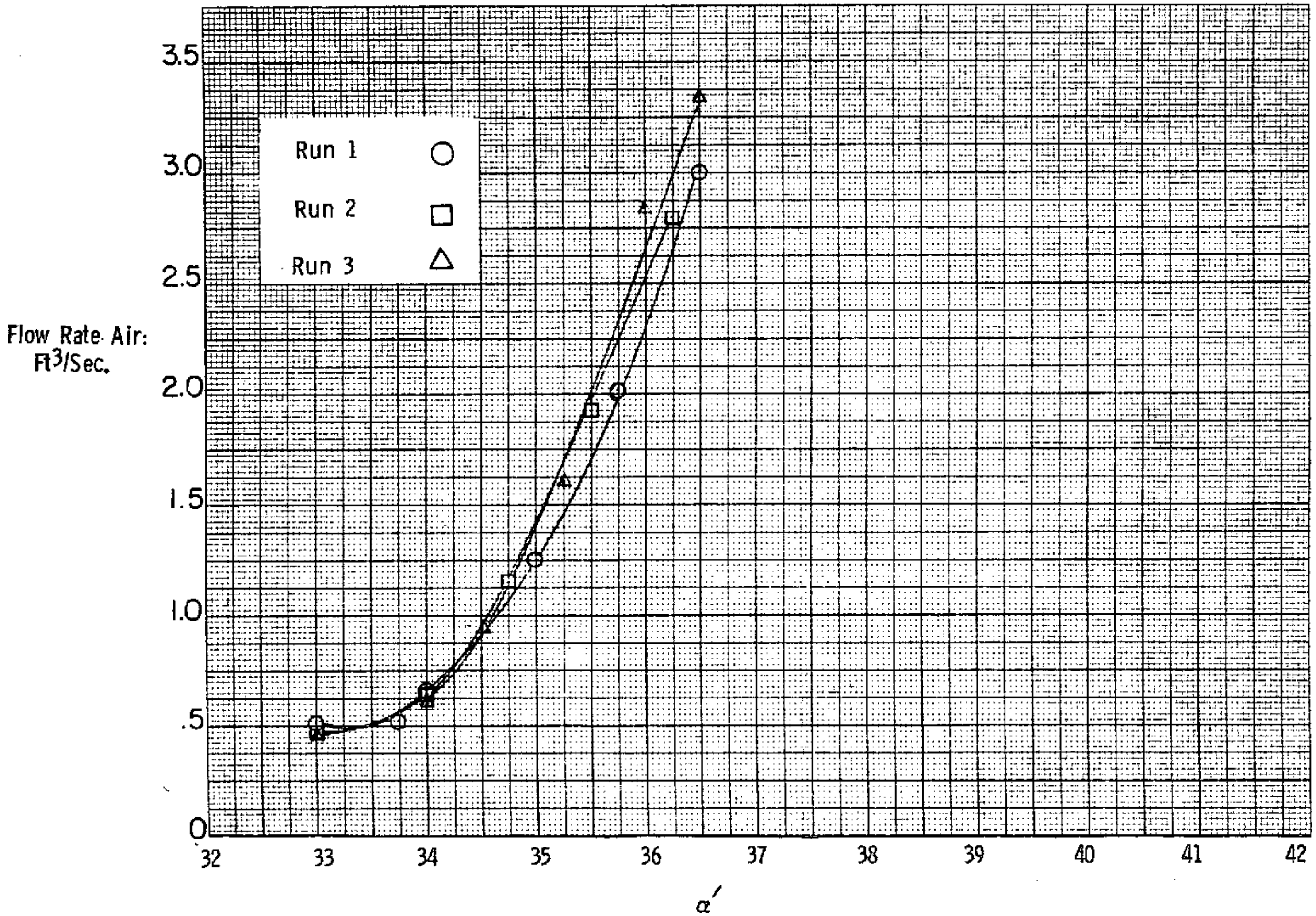


Figure 7.- Amount of blowing from reflection plane, nozzle flush, needed to prevent bursting of leading-edge vortex at trailing edge, $L/C = 0.25$.



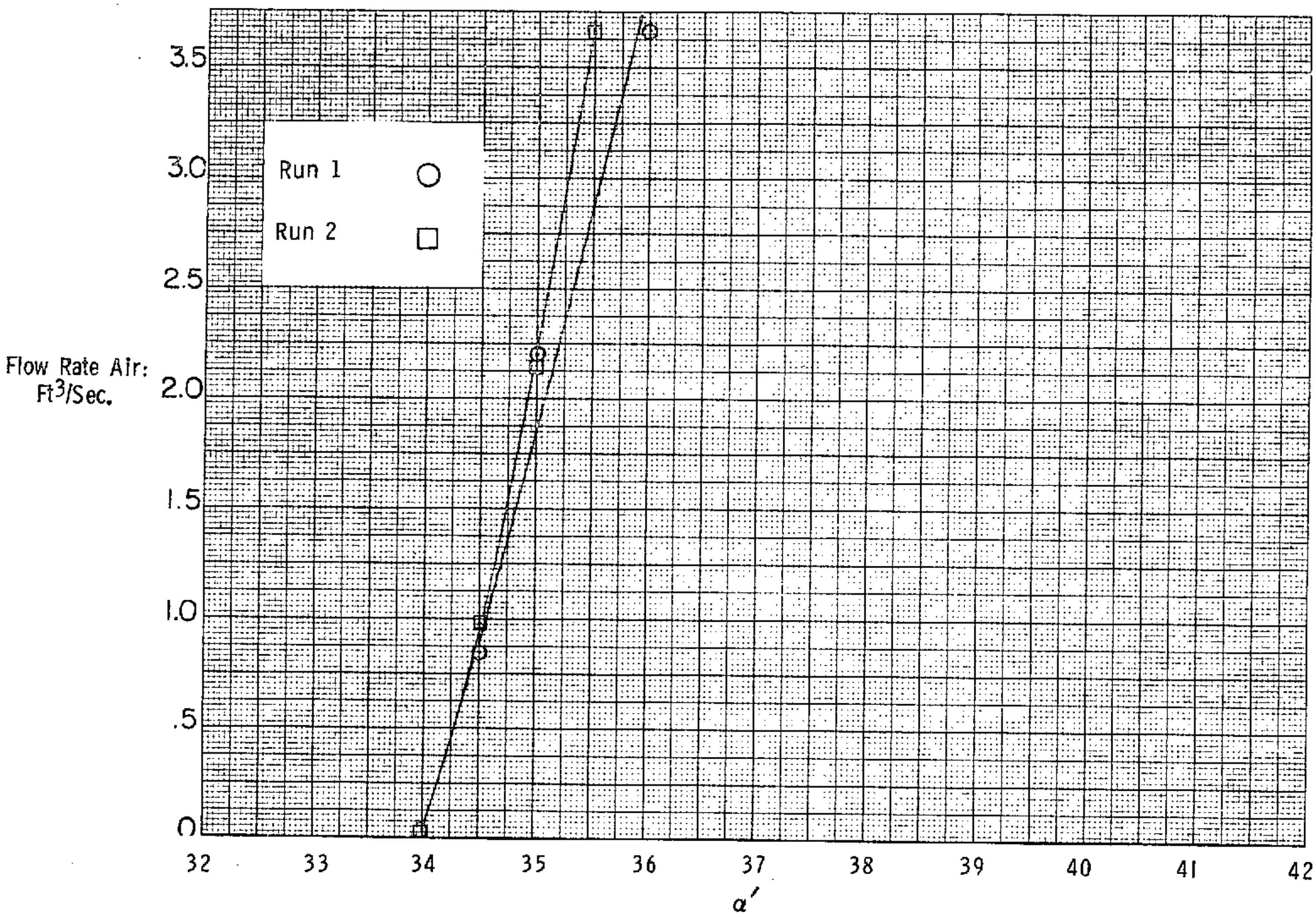
(b) L/C = 0.25, nozzle extended.

Figure 7.- Continued.



(c) L/C = 0.34, nozzle extended

Figure 7.- Continued.



(d) L/C = 0.34, nozzle flush

Figure 7.- Concluded.

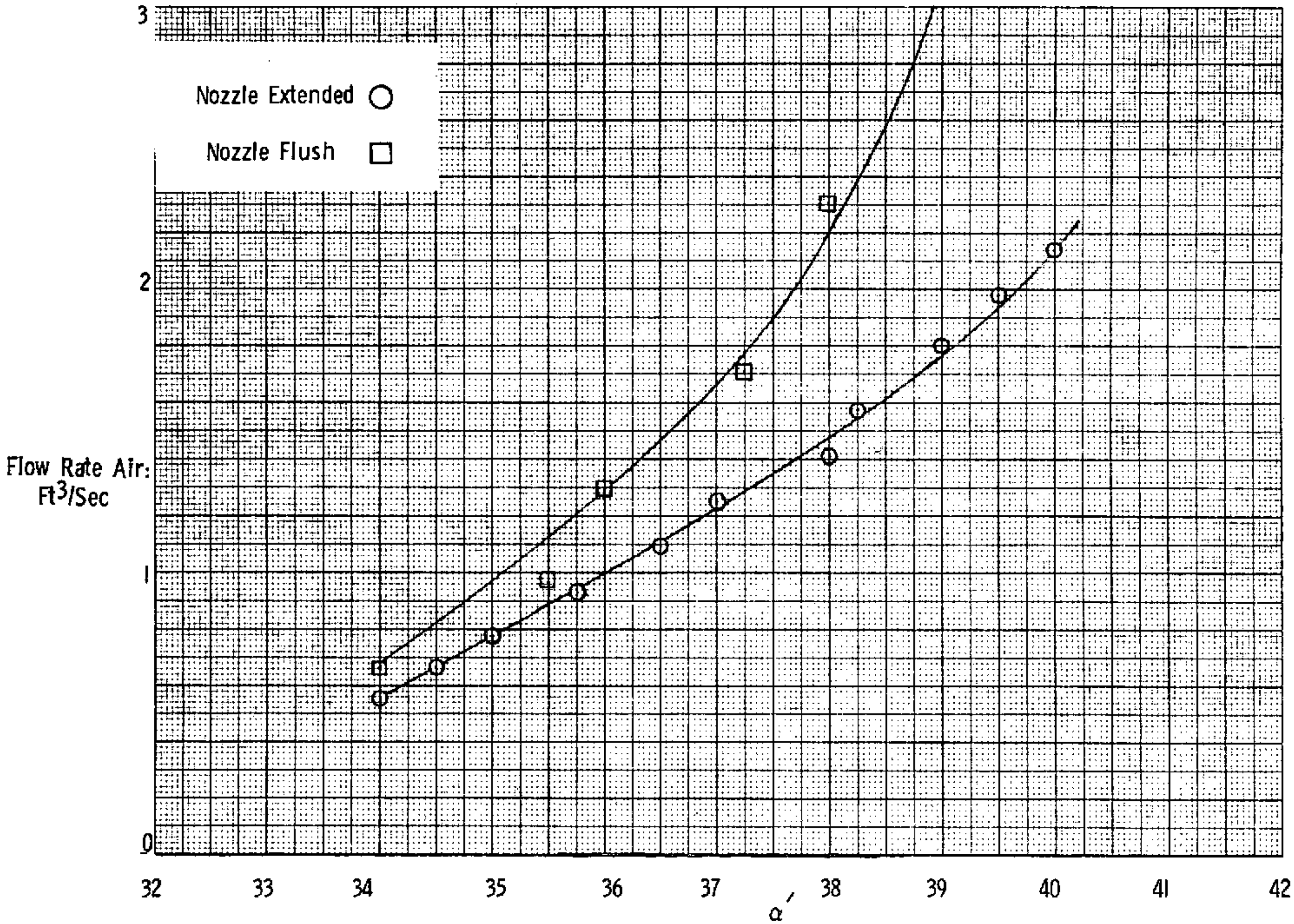
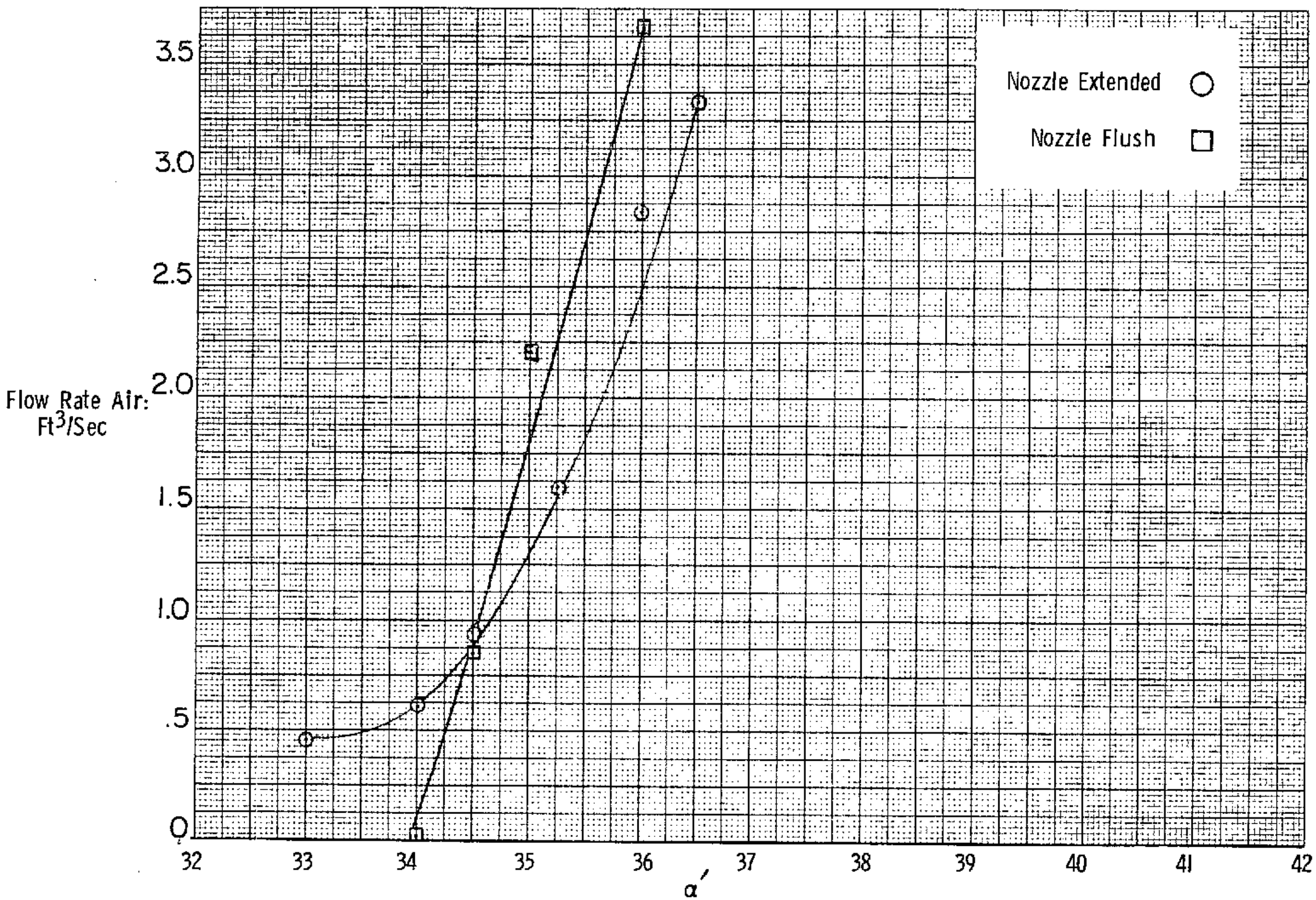


Figure 8. - Averaged data-Blowing from reflection plane, L/C=0.25.



(b) L/C = 0.34

Figure 8.- Continued.

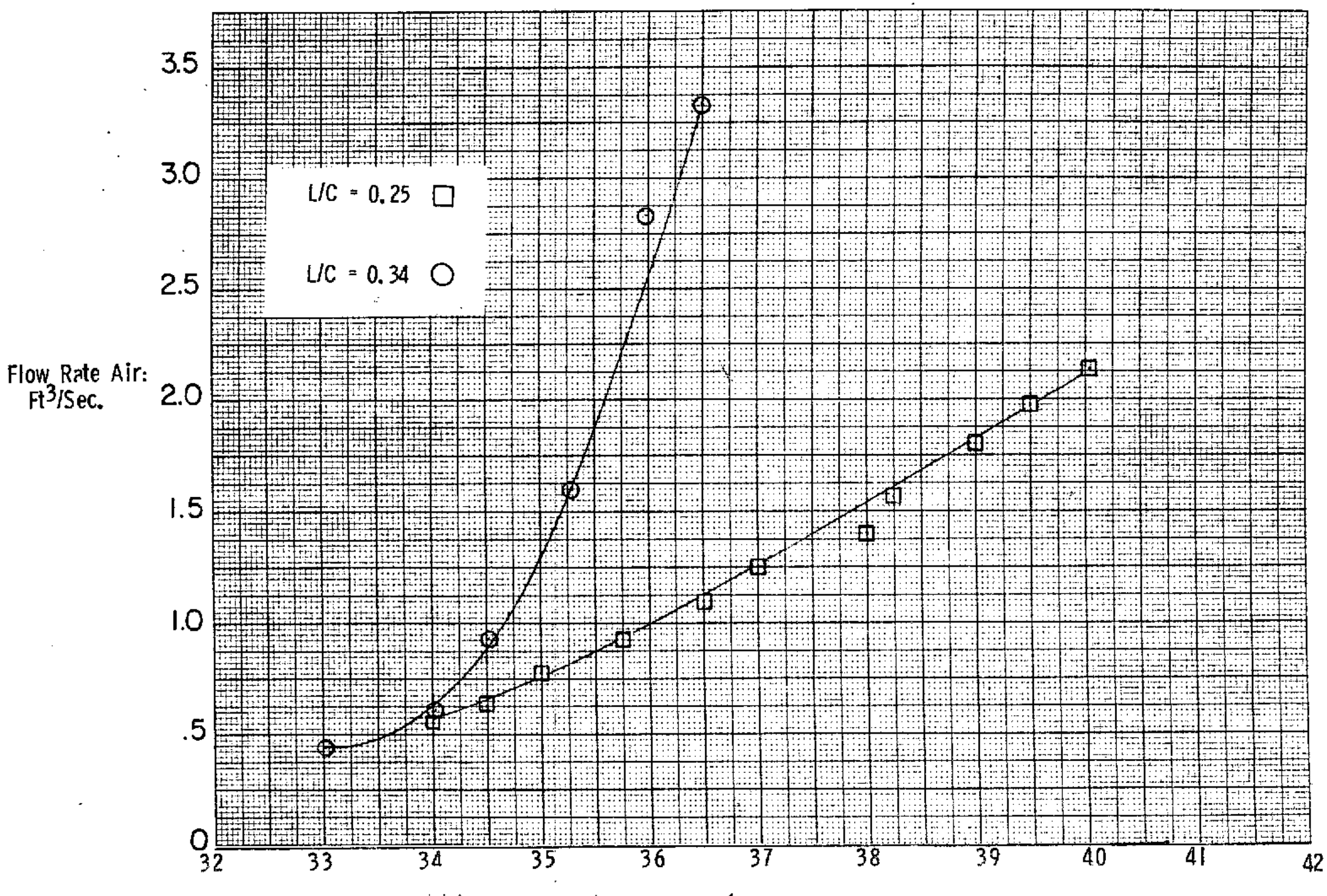
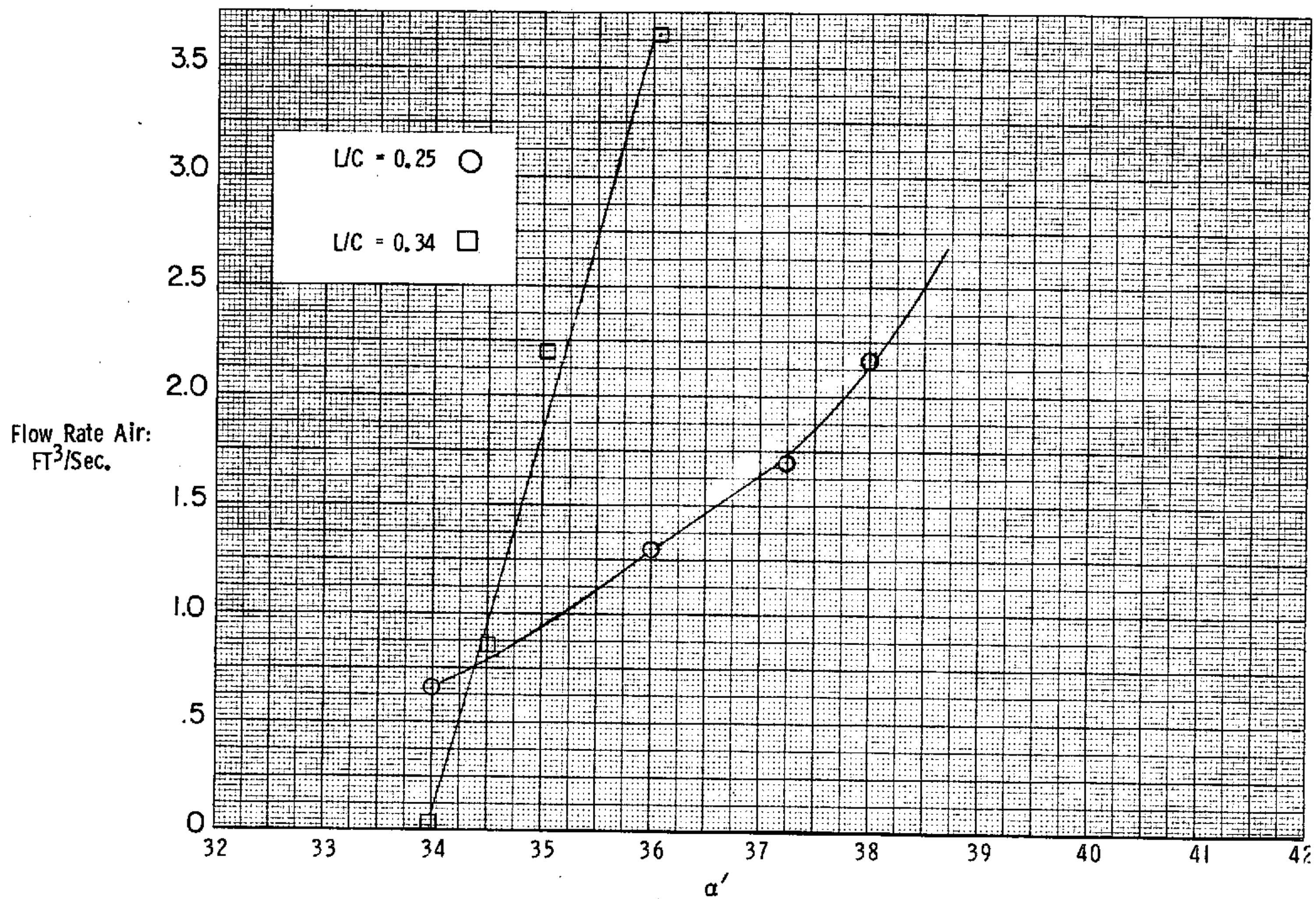


Figure 9.- Comparison of L/C = 0.25 and 0.34 locations in blowing from reflection plane, nozzle extended.



(b) Nozzle Flush

Figure 9.- Continued

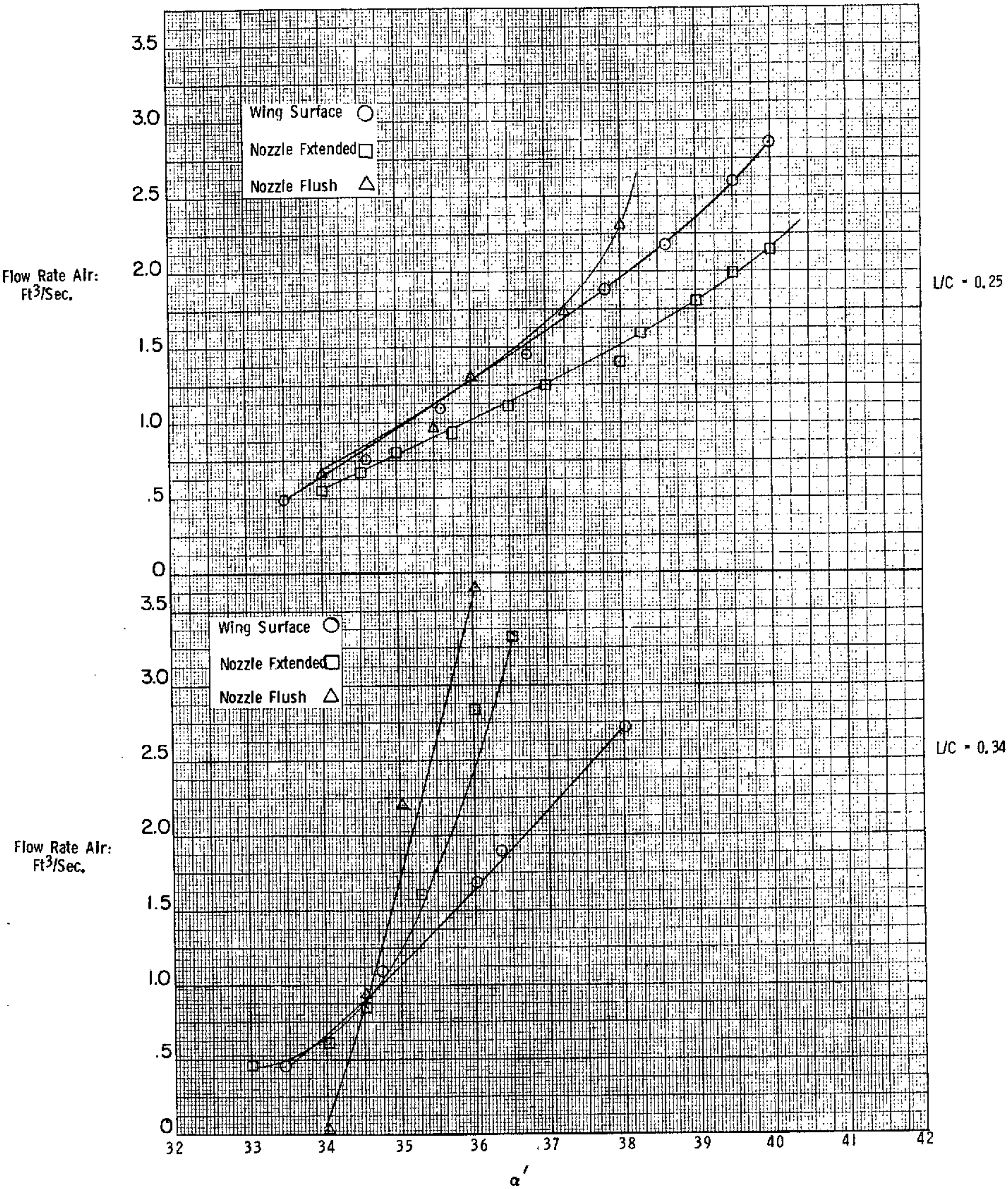


Figure 10.- Comparison of reflection plane and wing surface blowing.