MR No. A4L14

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, U.S. Army Air Forces

POWER-OFF TESTS OF THE NORTHROP N9M-2 TAILLESS AIRPLANE IN THE 40- BY 80-FOOT WIND TUNNEL

By Victor I. Steven, Jr., and Gerald M. McCormack

Ames Aeronautical Laboratory
Moffett Field, Calif.

December 14, 1944

[redacted]

No. 14

DECLASSIFIED

SINGLE COPY ONLY

MR No. A4L14 [redacted] DECLASSIFIED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, U.S. Army Air Forces

POWER-OFF TESTS OF THE NORTHROP N9M-2 TAILLESS AIRPLANE IN THE 40- BY 80-FOOT WIND TUNNEL

By Victor I. Stevens, Jr., and Gerald M. McCormack

SUMMARY

The Northrop N9M-2 airplane has been tested in the 40- by 80-foot wind tunnel to evaluate the airplane efficiency factor and to investigate the characteristics of the aeroboost in the elevon control system. Meager flight-test results had indicated a low airplane efficiency factor; however, the test results reported herein indicate an airplane efficiency factor of 0.80 for the airplane in the clean configuration at a test speed of 100 miles per hour. This value compares reasonably well with those obtained on conventional airplanes.

The aeroboost system appeared satisfactory, although modifications are necessary to fully utilize the balance pressures available. The ineffectiveness of the system was traced to leakage within the aeroboost valve. It is estimated that when the leakage can be eliminated, the range of elevon deflections available by aeroboost will be increased

[redacted]

about 70 percent.

Valve-chatter tests indicated that the chatter was not severe and that a valve spring with the proper preload should remove any tendency for chatter except possibly at very high flight speeds. In the pilot's opinion, the aeroboost was sufficiently perfected to allow flight tests of the N9M-2 without incurring any undue risk.

INTRODUCTION

The Northrop N9M-2 airplane is a flying model of the proposed XB-35 airplane. Small-scale wind-tunnel models of the XB-35 have previously been tested to obtain the general airplane characteristics (references 1 and 2). The purpose of the wind-tunnel tests of the N9M-2 reported herein was (1) to evaluate the airplane efficiency factor which was reported from meager flight-test data to be low, and (2) to determine the characteristics of the aeroboost in the elevon control system.

Because of the size of the XB-35, a boost will be needed in the elevon control system to bring control forces within the desired limits. The aeroboost system was designed by Northrop Aircraft, Inc., and installed in the N9M-2. Since the aeroboost system was new and little information existed concerning its characteristics, wind-tunnel tests were desired prior to actual flight tests to indicate the safety and adequacy of the balance system for use in flight and, further, to indicate possible improvements.

DESCRIPTION OF AIRPLANE

The N9M-2 airplane is a flying model (approx. 35-percent scale) of the proposed XB-35 flying-wing bomber, but differs from the XB-35 in that it is propelled by two pusher propellers rather than four. Figure 1 presents a three-view drawing of the N9M-2, and figure 2 shows the airplane mounted in the tunnel. Notable geometric characteristics of the wing are high taper and sweepback, pitch flaps near the wing tips to trim the airplane when the landing flaps are deflected, and true-profile elevons which may be moved together as elevators or moved differentially as ailerons. The basic dimensions of the airplane are given in table I.

The elevons are provided with an aeroboost system to reduce control-column forces. In figure 3 are presented schematic diagrams of the aeroboost ducting system and control linkage. As will be noted from the diagrams, any differential movement between the control column and elevon, produced by the elevon resisting the control-column movement, actuates the valve. The valve then directs impact pressures from the scoop, and static pressures from the exit, to the balance chambers, in order to balance the external air forces on the elevon. The elevon control system is provided with a follow-up mechanism which gives direct pilot control over the elevon after the valve has reached its open or closed limit. Thus, if a fully open or closed valve does not provide sufficient pressure differential between the balance chambers to enforce the desired elevon movement, the follow-up mechanism automatically transmits any additional stick-force directly to the elevon. Also, due to the follow-up mechanism, the control-column position is essentially proportional to the elevon deflection.

TESTS AND PROCEDURE

For the drag tests the airplane was mounted as an airfoil is normally mounted in the tunnel. The main airplane support struts and angle-of-attack links were attached to fittings on the main spar and rear spar, respectively. Strength limitations of the airplane structure at the points of attachment required that the test speed be kept under 100 miles per hour (Reynolds number = 8,400,000) and that the pitching moments be low. The surface of the wing was painted and sanded prior to the tests, giving an aerodynamically clean but not highly polished surface. No attempt was made to seal or fair the inspection-hole covers, since it was desired to obtain the drag of the airplane in the normal flight configuration.

Since use of the airfoil mounting system necessitated very low test velocities with the elevons deflected, due to the low strength of the rear spar at the points of attachment to the angle-of-attack links, tests of the aeroboost system were made with the airplane mounted on the normal three-strut airplane support system. A tail boom connecting the airplane to the rear airplane support strut was substituted for the angle-of-attack links, movement of the rear support strut controlling the angle of attack. Duplicate tests were made with the airplane mounted as an airfoil and mounted on the three-strut support to assess the tare of the tail boom.

The static aeroboost characteristics were obtained by holding various fixed angles of attack and varying the valve position throughout its operating range. Force-test data, impact pressure in the scoop, static pressure in the exit, pressure differential between the balance chambers, elevon position, and valve position were recorded for each valve setting. Hinge moments were determined by use of a ground calibration of hinge moment against pressure differential between the balance chambers. For these tests the follow-up mechanism was removed.

Dynamic characteristics of the aeroboost system were obtained with a pilot at the controls to obtain his reaction to the aeroboost characteristics and to determine the effect on valve chatter of damping springs attached to the valves. Tests were made at various angles of attack and speeds with various damping springs on the valves (with the follow-up mechanism in place) to study the valve-chatter characteristics. Control response was also studied at various speeds and attitudes.

Continuous oscillograph records were made of dynamic characteristics of the aeroboost system for various control movements. A typical example of these records is presented in figure 4. Due to bulkiness, the complete records are not presented in this report but are retained in the Ames Laboratory files.

RESULTS AND DISCUSSION

The test results presented in this report are in the form of standard NACA coefficients which are defined in table II. The pitching moments are referred to a center of gravity located 25 percent M.A.C. aft of the M.A.C. leading edge and 4.19 percent M.A.C. above the root chord. All data have been corrected for support tares, flow inclination, tunnel-wall effects, and tail-boom effect where the tail boom was used.

The results of tests to evaluate the airplane efficiency factor are presented in figure 5 for test speeds of 100 miles per hour (R = 8,400,000) and 80 miles per hour (R = 6,600,000). For these tests the airplane was in the clean configuration with the aeroboost scoops removed and the exits sealed (to correspond to previous flight-test configurations). For a test speed of 100 miles per hour, the airplane efficiency factor e is 0.80 over the range of lift coefficients tested. When the test speed was reduced to 80 miles per hour, the value of e was greater than 0.80 for lift coefficients below 0.5 and less than 0.80 for higher lift coefficients. These values compare reasonably well with those for conventional airplanes.

The above data have been replotted in figure 6 to a minimum-drag scale. At a lift coefficient of 0.1 (approximate high-speed lift coefficient), drag coefficients of 0.0129 and 0.0123 were measured for test speeds of 100 miles per hour and 80 miles per hour, respectively.

An attempt was made to determine the effect of the aeroboost scoops and exit slots on the lift, drag, and pitching-moment characteristics of the airplane. As shown in figure 7, the scoop and exit had little effect on the lift and pitching-moment characteristics. In figure 8 it will be noted that at a lift coefficient of 0.1 the scoops produced a drag-coefficient increment of 0.0007, but that unsealing the exit slots reduced the drag. It is probable that the drag reduction realized by opening the slots was due to leakage through the aeroboost valve from scoops to exits, causing a reduction in the drag of the scoops.

Figures 9(a) and 9(b) present the effect of elevon deflection on the aerodynamic characteristics of the airplane and on the general characteristics of the aeroboost system.

It is to be noted in figure 9(b) that a fully open or fully closed valve gives only about one-half the pressure differential between the balance chambers that is available between scoop and exit. Visual observations taken during the tests indicated that practically the entire pressure loss occurred within the valve as leakage between impact and static ducts. Further evidences of valve inefficiency are the differential pressures, indicated by the flagged symbols of figure 9(b), which were obtained with the valve fully closed and the impact passage to the lower balance chamber sealed off. (Because of the inaccessibility of the passage which directed static pressure to the valve for the upper balance chamber, sealing off this passage would have required too much time; consequently, this modification was not made.) The resulting pressure differential between the balance chambers was 15 to 50 percent higher than was previously obtained. If it had been feasible to seal off the static passage to the upper balance chambers, it is probable that much greater gains would have been realized.

An improved valve having no leakage and giving full available pressure differential between the balance chambers should give elevon deflections which could be approximated by continuation of the curves of figure 9(b) to the point where the full available pressure exists between the balance chambers. For airplane velocities within the normal flight range, a summary is presented in figure 10 of (1) elevon deflection required for longitudinal trim for level flight with center of gravity located at 25 percent of the mean aerodynamic chord, (2) elevon deflections attainable with the present aeroboost system, and (3) elevon deflections which, it is estimated, would be obtainable if no leakage occurred within the valve. As shown in figure 10, with the present aeroboost approximately 7° up elevon and 10° down elevon can be realized beyond that required for longitudinal trim for level flight throughout the flight range; whereas, if leakage were eliminated in the valves, approximately 12° up elevon and 18° down elevon would be realized beyond that required for trim (c.g. at 25 percent M.A.C.). The pilot can obtain greater deflection through the follow-up mechanism as previously described.

The preliminary valve-chatter tests indicated that the chatter was not severe, and that it could be started only at the higher test speeds and for a very limited elevon-angle range. Since any amount of chatter is undesirable, an attempt was made to eliminate the chatter tendencies by introduction of a valve damping spring in the aeroboost system. It was observed that at each airplane attitude there was a test speed below which chatter could not be started and, further, that as the preload on the damping spring was increased the minimum velocity for chatter was increased. These test results are shown graphically in figure 11 where, for various valve springs, the minimum speed for chatter is plotted against airplane lift coefficient. The intersections of these curves with the level-flight curve (also shown in fig. 11) indicate the lowest speeds at which chatter can be induced in level flight. With the greater spring preload, this speed was over 145 miles per hour, a gain of more than 45 miles per hour above the value for no spring. (The value of 145 miles per hour is arrived at from a conservative extrapolation. Airplane structural limitations on test speed prevented testing at sufficiently high velocity in the tunnel to attain the minimum speed for chatter at low lift coefficients with spring 2 installed.) Based upon these results it appears that a valve spring with the proper preload should remove any tendency for chatter, except possibly at very high flight speeds.

In the pilot's opinion the aeroboost was sufficiently perfected to allow flight tests of the N9M-2 without incurring any undue risk.

CONCLUDING REMARKS

The airplane efficiency factor for the N9M-2 is not as high as might be expected from a flying-wing design, but compares reasonably well with the efficiency factors for conventional design. Although the aeroboost system as tested appeared sufficiently perfected to allow flight tests of the N9M-2 airplane in comparative safety, it is felt that an attempt should be made to eliminate the valve leakage prior to flight tests.

National Advisory Committee for Aeronautics,
Ames Aeronautical Laboratory,
Moffett Field, Calif., December 14, 1944.

Victor I. Stevens, Jr.,
Aeronautical Engineer.

Gerald M. McCormack,
Mechanical Engineer.

Approved:

John F. Parsons,
Aeronautical Engineer.

REFERENCES

1. Sivells, James C., and Burgess, Jack: Tests in the 19-Foot Pressure Tunnel of a 1/10.75-Scale Model of the Northrop XB-35 Tailless Airplane. NACA CMR, Feb. 3, 1943.

2. Denaci, H.G., and Anderson, R.A.: Elevon Development for the XB-35 Airplane From Two-Dimensional Flow Tests. NACA CMR, Sept. 26, 1944.

TABLE I.- DIMENSIONS OF THE NORTHROP N9M-2 AIRPLANE[1]

Wing area	490 sq ft
Wing span	60 ft
Aspect ratio.	7.4
Taper ratio	4:1
Root chord.	13.08 ft
Theoretical section.	NACA 65,3-019
Enlarged section	NACA 65,3-024
Tip chord	3.25 ft
Theoretical section.	NACA 65,3-018
Mean aerodynamic chord.	9.17 ft
Dihedral (at 25 percent chord)	
Root chord to station 99	2°
Station 99 to tip.	$\frac{1}{2}^\circ$
Sweepback (at 25 percent chord) . . .	$21^\circ 56'$
Geometric washout at wing tip	4°
[2]Elevon area aft of hinge line (each).	17.15 sq ft
[2]Elevon chord aft of hinge line (constant)	1.60 ft
Gross weight.	6326 lb
Wing loading.	12.9 lb per sq ft
Center of gravity	25 percent M.A.C. aft of M.A.C. leading edge, 4.19 percent M.A.C. above root chord

[1] Dimensional data taken from Northrop Aircraft, Inc., drawing 506070 (drawn 11-7-41) except as noted.
[2] Measured dimension or deduced from measured dimension.

TABLE II.- COEFFICIENTS AND SYMBOLS FOR THE NORTHROP N9M-2 AIRPLANE

C_L	lift coefficient (L/qS)
C_D	drag coefficient (D/qS)
C_m	pitching-moment coefficient (M/qSc)
C_{h_e}	elevon hinge-moment coefficient (H/qS_ec_e)
L	lift, pounds
D	drag, pounds
M	pitching moment, foot-pounds
H	elevon hinge moment, foot-pounds. Positive hinge moment tends to deflect elevon downward.
q	dynamic pressure $(\frac{1}{2}\rho V^2)$, pounds per square foot
S	wing area = 490 square feet
c	mean aerodynamic chord of wing = 9.17 feet
S_e	area of elevon aft of hinge line = 17.15 square feet each
c_e	chord of elevon aft of hinge line = 1.60 feet
H_a	impact pressure in aeroboost scoop, pounds per square foot
p_a	static pressure in aeroboost exit, pounds per square foot
Δp	pressure differential between upper and lower balance chambers, pounds per square foot
R	test Reynolds number based on mean aerodynamic chord $(\rho Vc/\mu)$

TABLE II.- CONCLUDED. NORTHROP N9M-2 AIRPLANE

e	airplane efficiency factor $\left(\frac{1/\pi A}{dC_D/dC_L{}^2}\right)$
A	aspect ratio = 7.4
ρ	mass density, slugs per cubic foot
V	velocity, feet per second
μ	viscosity, pound-seconds per square foot
α	corrected angle of attack of root chord, degrees
α_u	uncorrected angle of attack of root chord, degrees
δ_e	elevon deflection, degrees. Positive deflection downward.

FIGURE LEGENDS

Figure 1.- Three-view drawing of Northrop N9M-2 airplane.

Figure 2.- The Northrop N9M-2 airplane mounted in the NACA 40- by 80-foot tunnel. (a) Three-quarter front view from below. (b) Three-quarter front view from above.

Figure 3.- Aeroboost ducting system and control linkage for Northrop N9M-2 airplane.

Figure 4.- Typical example of oscillograph records (reduced) of dynamic characteristics of aeroboost system of Northrop N9M-2 airplane.

Figure 5.- Variation of drag coefficient with lift coefficient squared for Northrop N9M-2 airplane. Complete airplane with scoops off and exits sealed.

Figure 6.- Effect of dynamic pressure on minimum drag coefficient of Northrop N9M-2 airplane.

Figure 7.- Effects of aeroboost scoops and exits on aerodynamic characteristics of Northrop N9M-2 airplane. Dynamic pressure, 15 lb/sq ft; Reynolds number, 6.6×10^6.

Figure 8.- Effect of aeroboost scoops and exits on minimum drag of Northrop N9M-2 airplane. Dynamic pressure, 15 lb/sq ft; Reynolds number, 6.6×10^6.

Figure 9.- Characteristics of the aeroboost system at various angles of attack for Northrop N9M-2 airplane. (a) C_L, C_m, C_{h_e} vs δ_e.

Figure 9.- Concluded. (b) Valve position, $\frac{H_a - p_a}{q}$, $\frac{\Delta p}{q}$ vs δ_e. Northrop N9M-2 airplane.

Figure 10.- Comparison of elevon deflection required for trim, elevon deflection available with present aeroboost system, and elevon deflection possible with no valve leakage for Northrop N9M-2 airplane.

Figure 11.- Effect of aeroboost valve springs on the minimum velocity at which chatter occurred. Northrop N9M-2 airplane.

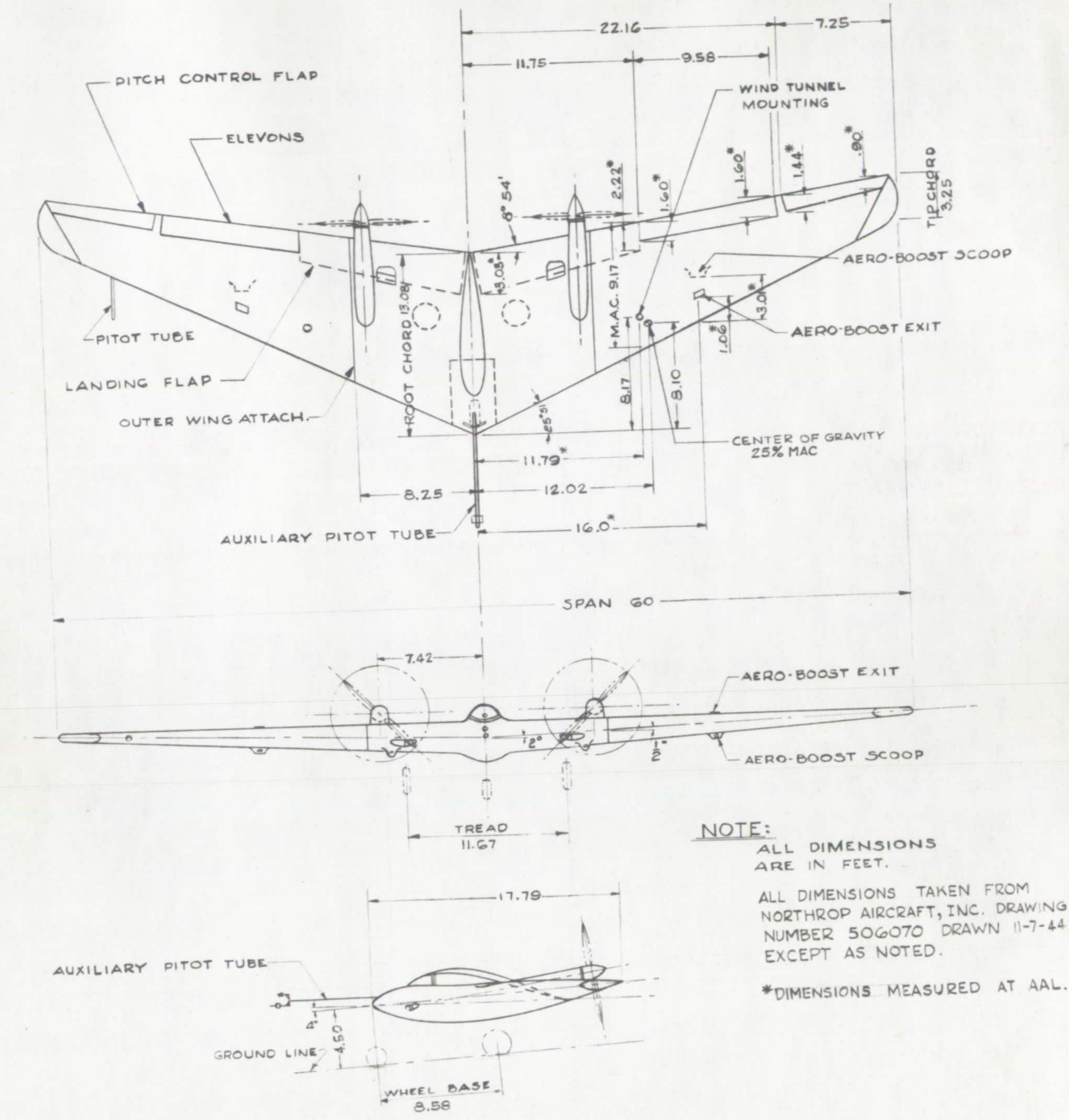
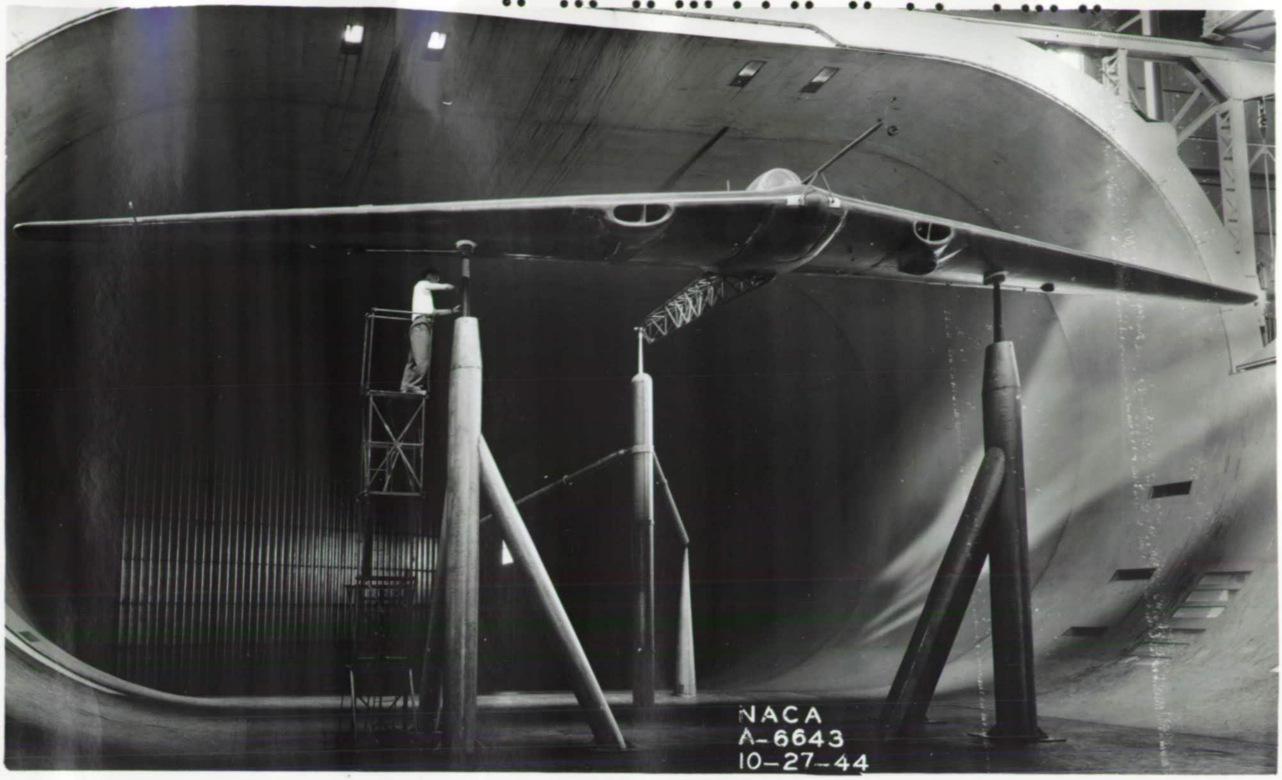
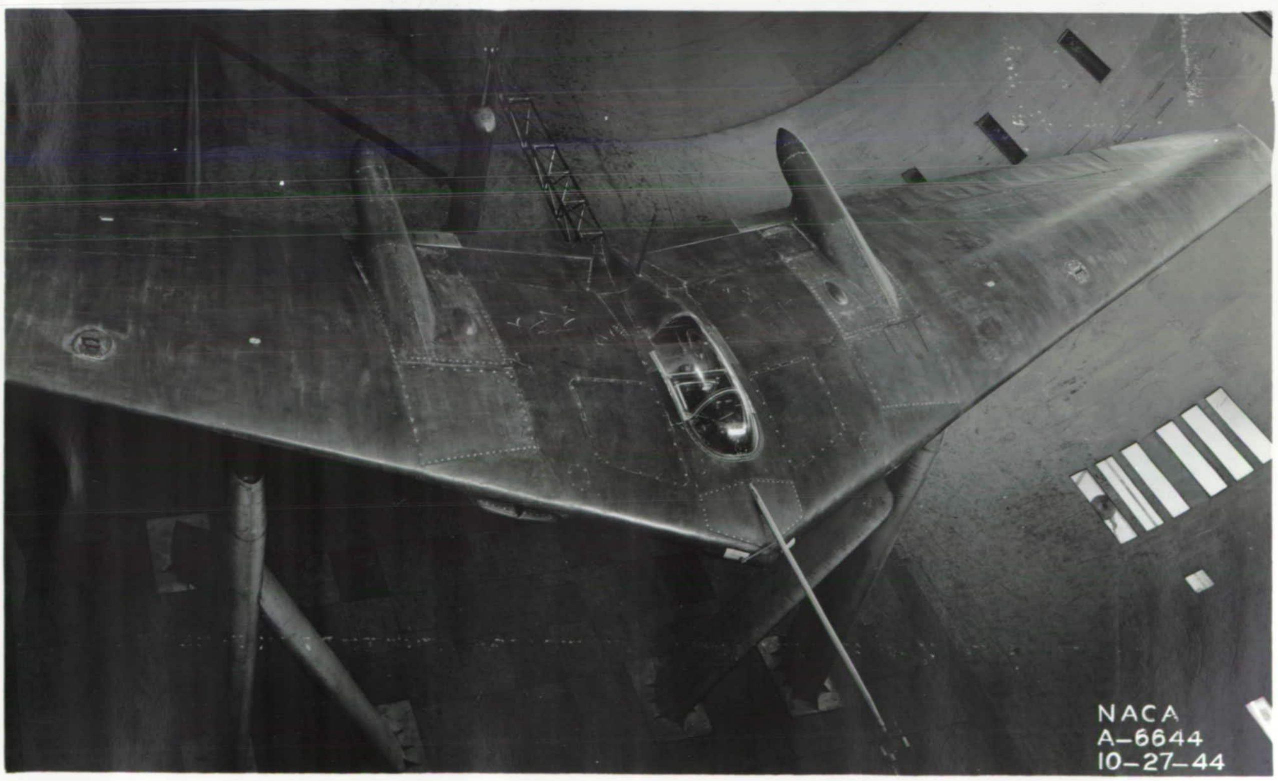


FIGURE 1. - THREE-VIEW DRAWING OF NORTHROP N9M-2 AIRPLANE

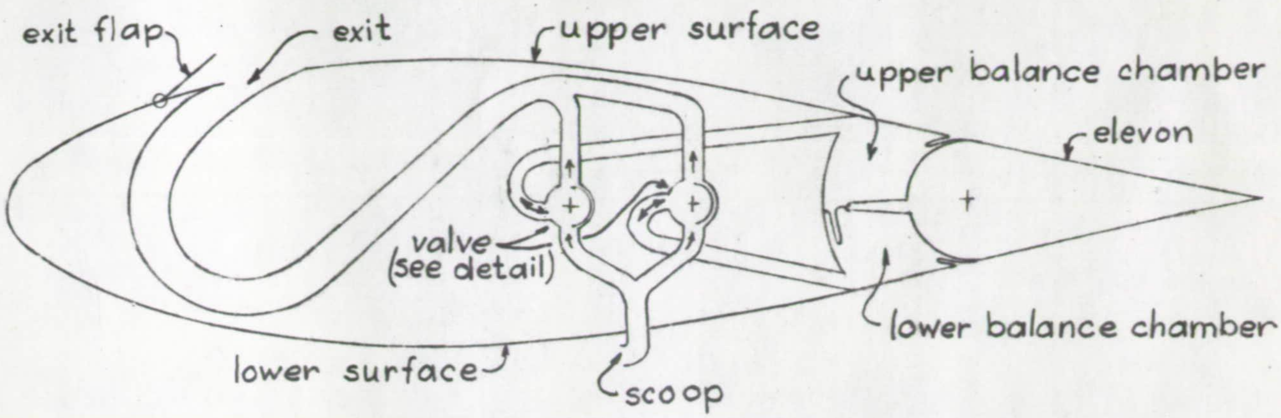


(a) Three-quarter front view from below.

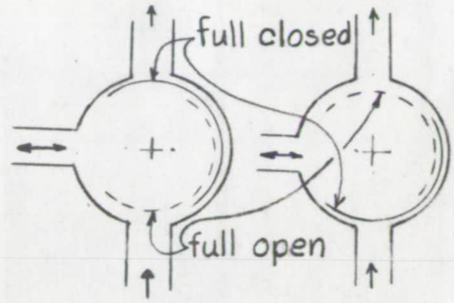


(b) Three-quarter front view from above.

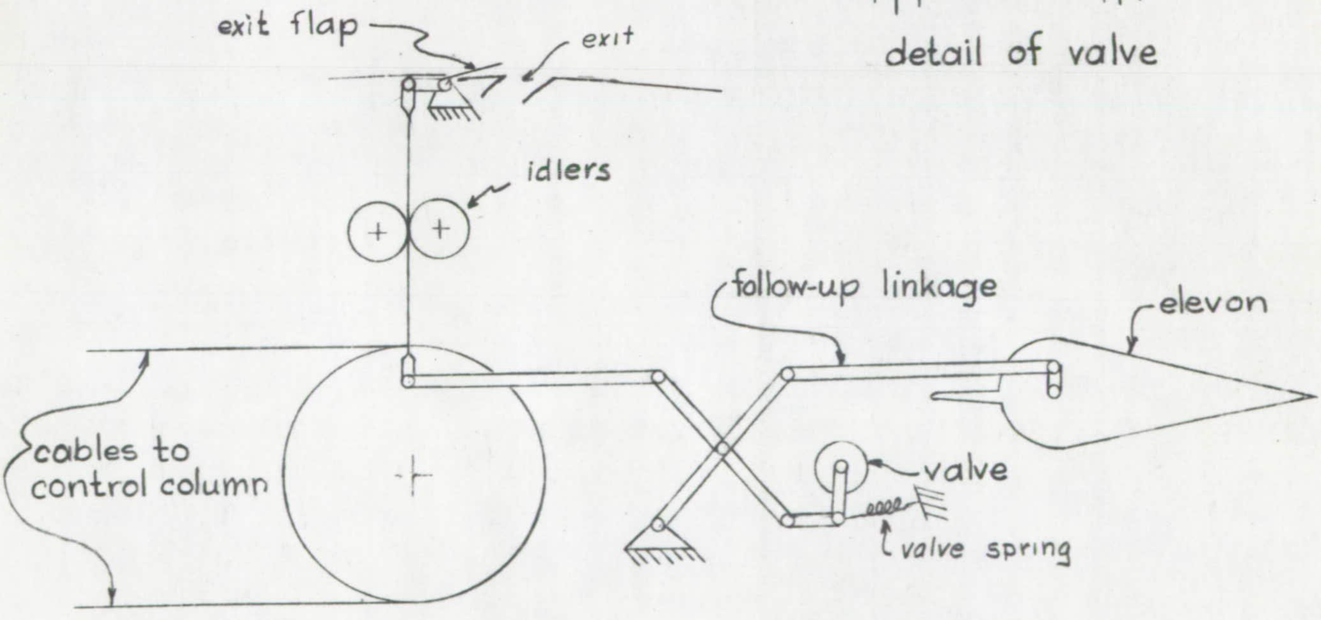
Figure 2.- The Northrop N9M-2 airplane mounted in the NACA 40- by 80-foot tunnel.



Schematic diagram of aero-boost ducting system



detail of valve



Schematic diagram of aero boost control linkage

Figure 3.- Aero boost ducting system and control linkage for Northrop N9M-2 airplane.

[redacted]

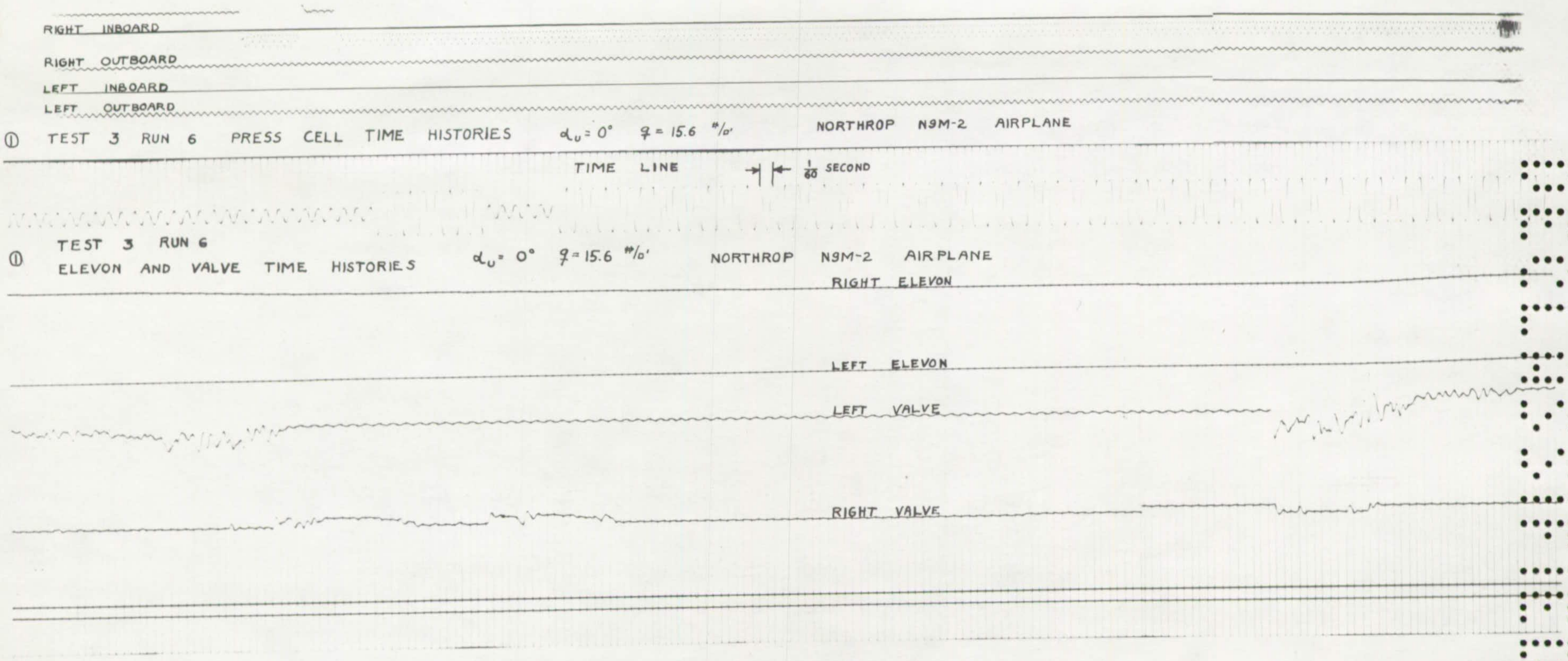


FIGURE 4.- TYPICAL EXAMPLE OF OSCILLOGRAPH RECORDS (REDUCED) OF DYNAMIC CHARACTERISTICS OF AERO-BOOST SYSTEM OF NORTHROP N9M-2 AIRPLANE

[redacted]

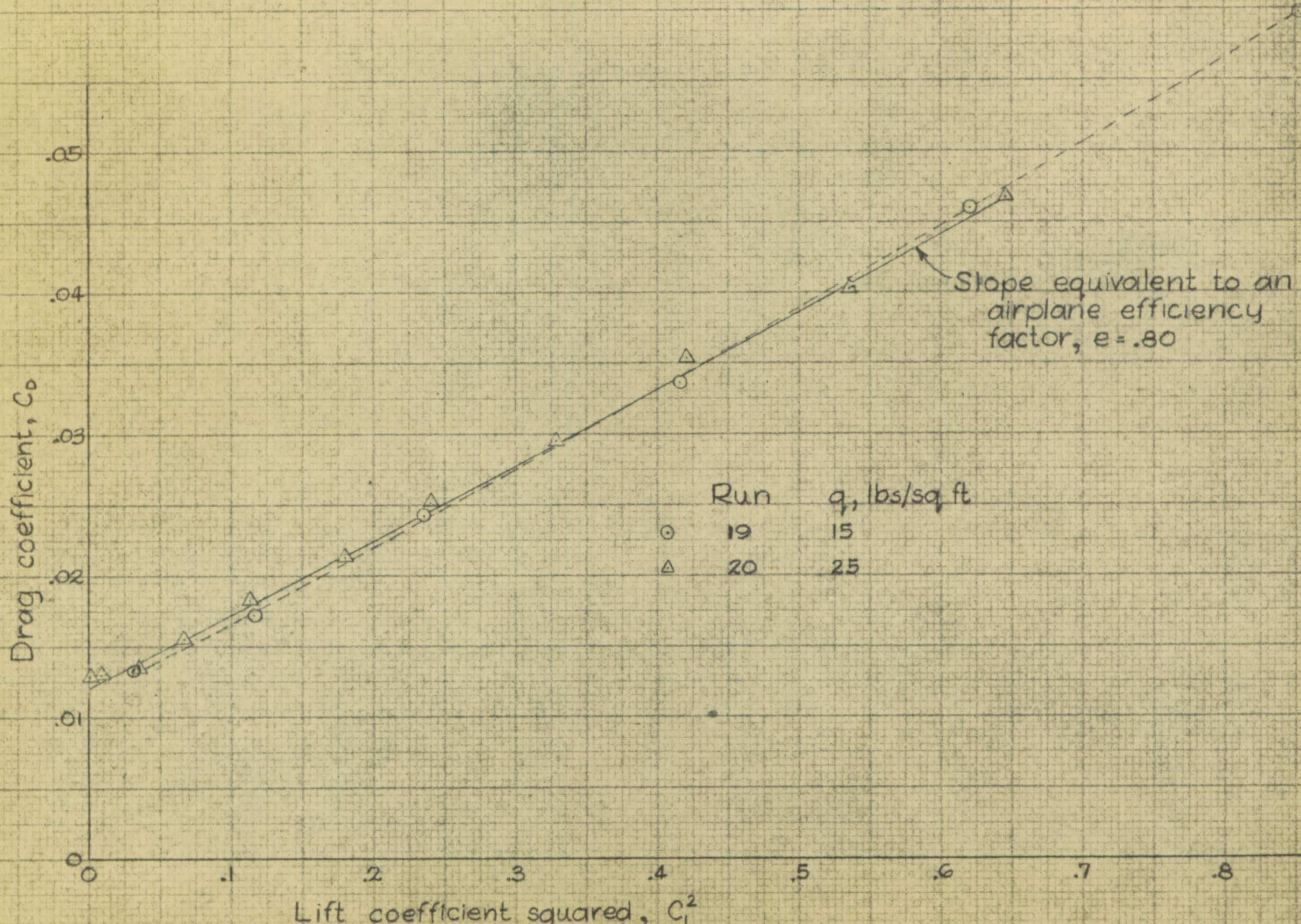


Figure 5.- Variation of drag coefficient with lift coefficient squared for Northrop N9M-2 airplane. Complete airplane with scoops off and exits sealed.

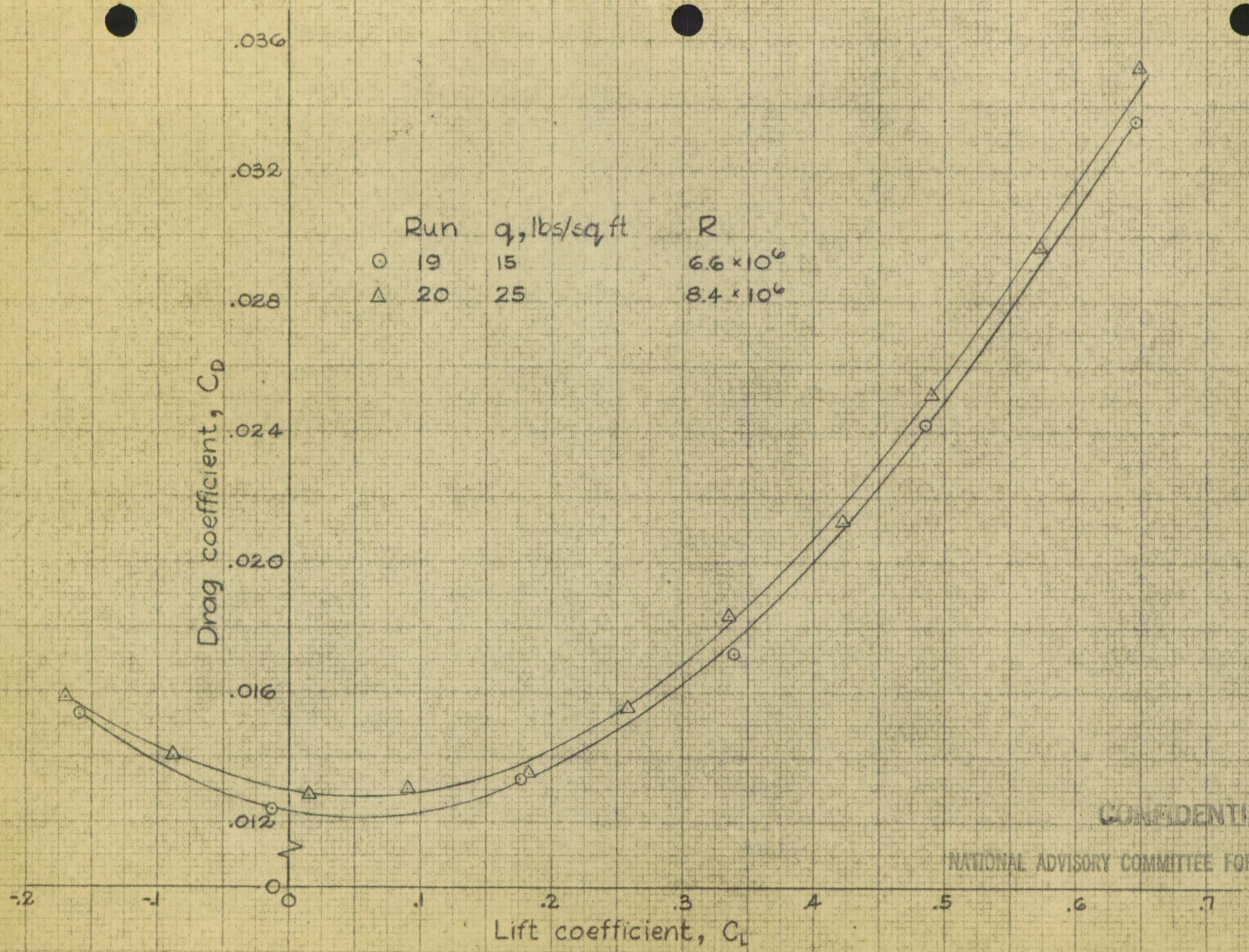


Figure 6.- Effect of dynamic pressure on minimum drag coefficient of Northrop N9M-2 airplane.

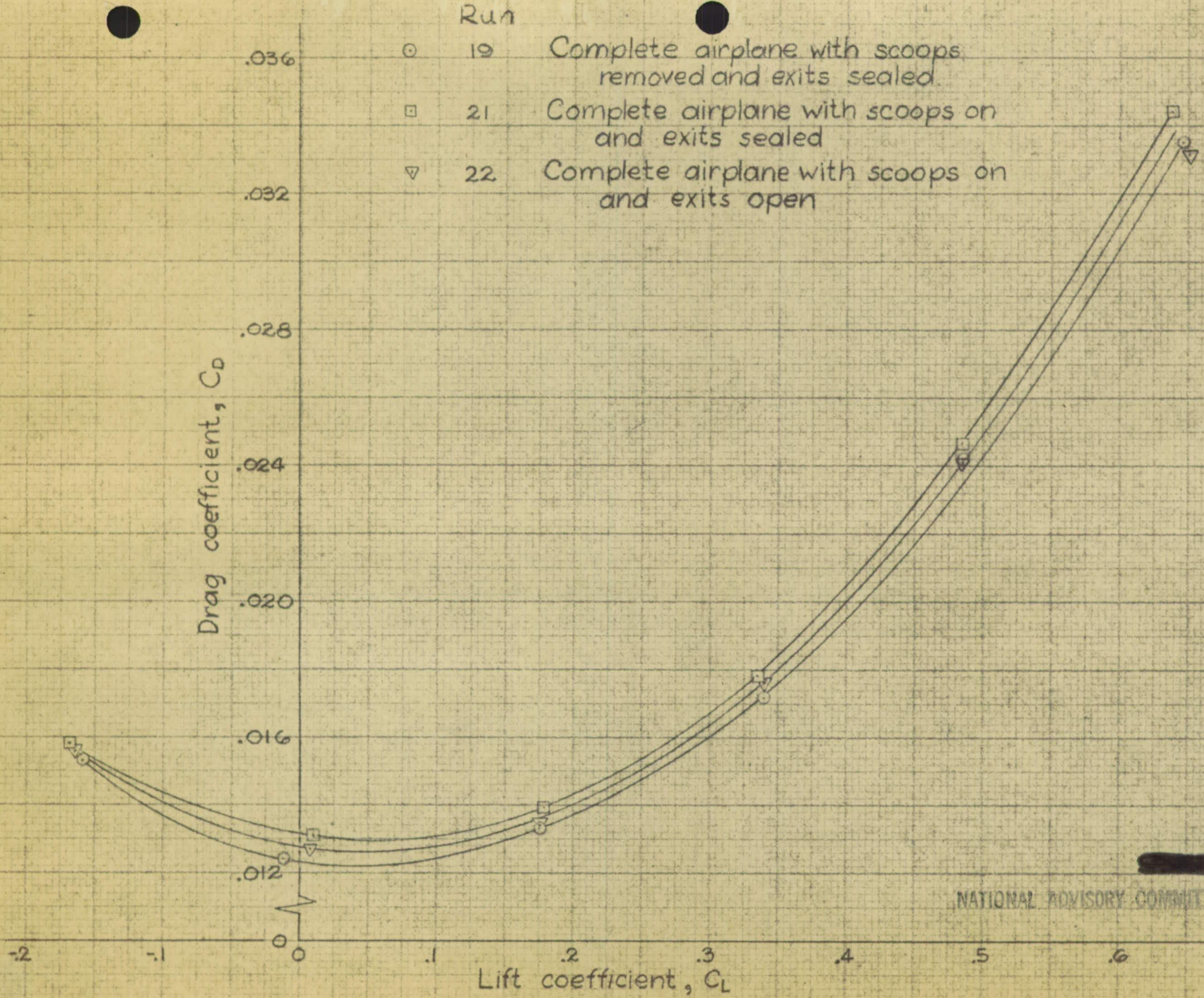


Figure 8. - Effect of aero boost scoops and exits on minimum drag of Northrop N9M-2 airplane. Dynamic pressure, 15 lb/sq ft; Reynolds number, 6.6×10^6.

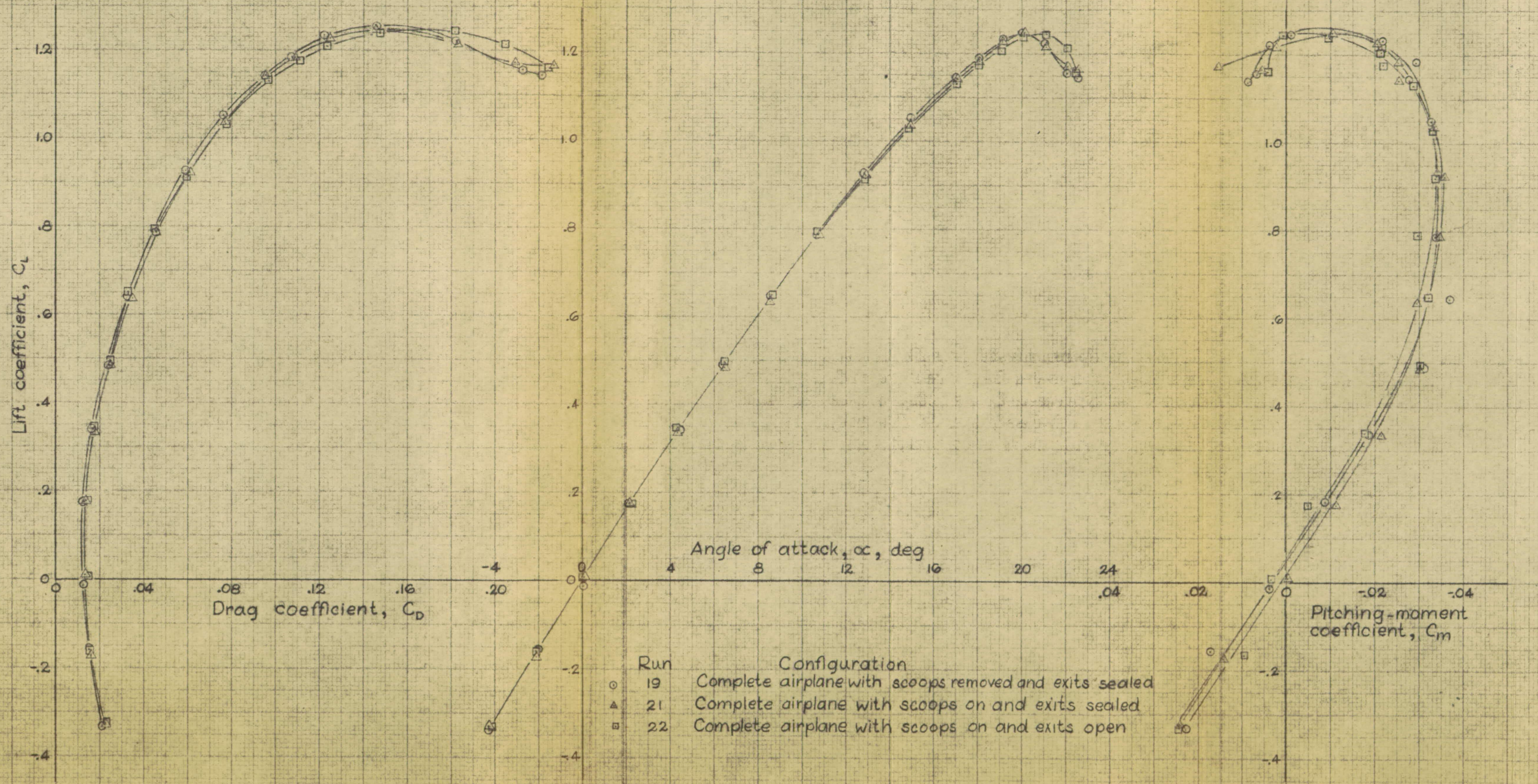
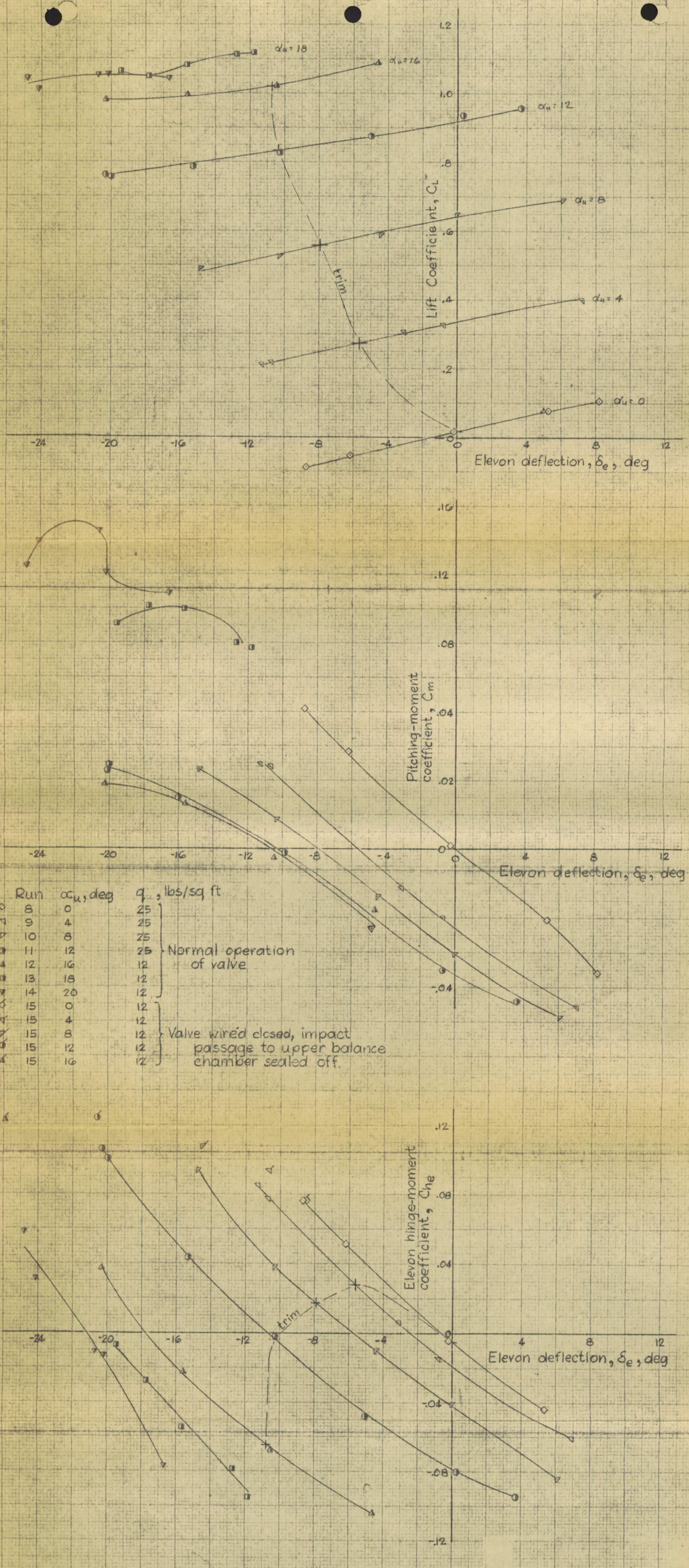
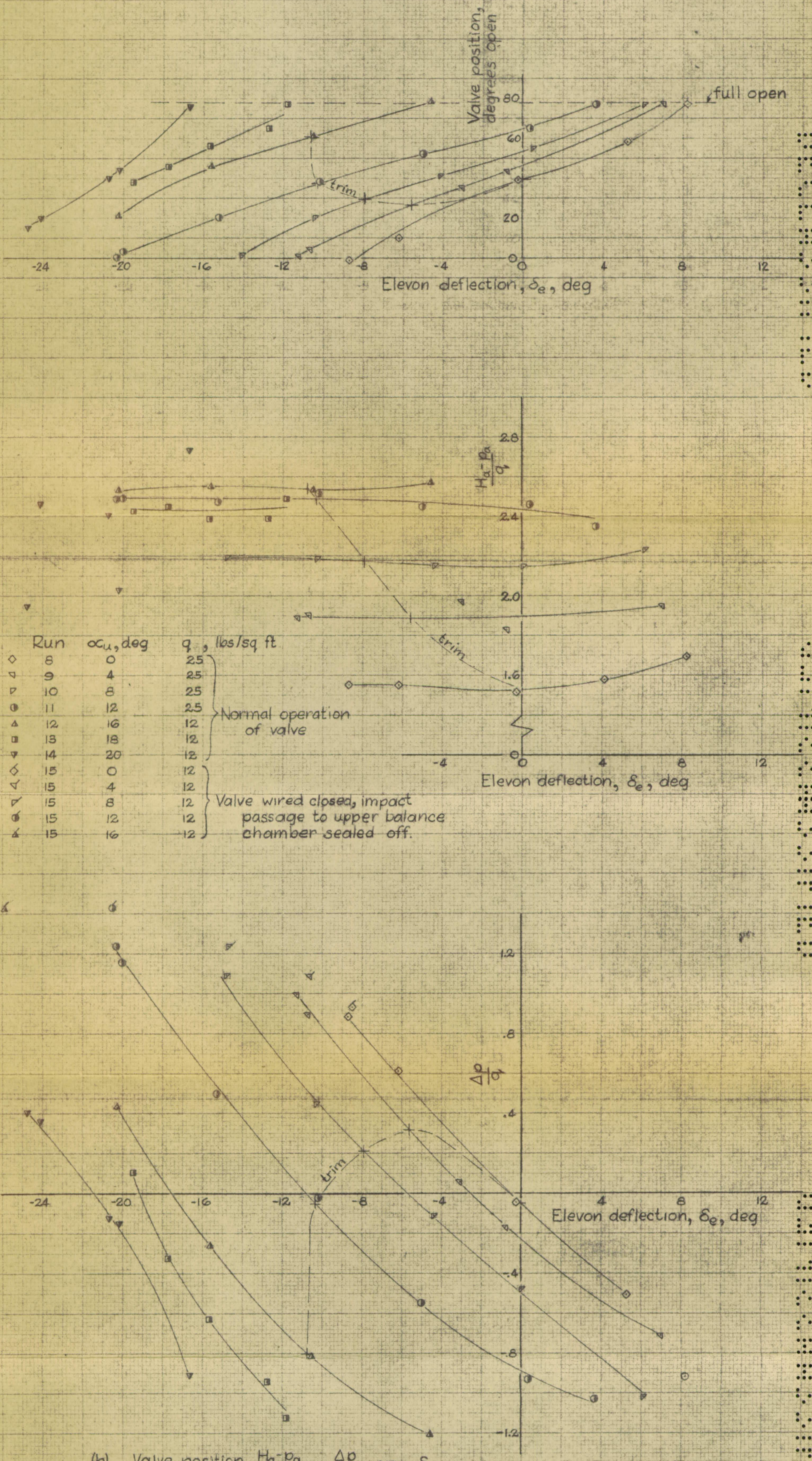


Figure 7.- Effects of aero boost scoops and exits on aerodynamic characteristics of Northrop N9M-2 airplane. Dynamic pressure, 15 lb/sq ft; Reynolds number, 6.6×10^6.



(a) C_L, C_m, C_{h_e} vs. δ_e

Figure 9.- Characteristics of the aero boost system at various angles of attack for Northrop N9M-2 airplane.



(b) Valve position, $\frac{H_a - p_a}{q}$, $\frac{\Delta p}{q}$ vs δ_e

Figure 9.- Concluded. Northrop N9M-2 airplane.

[redacted]

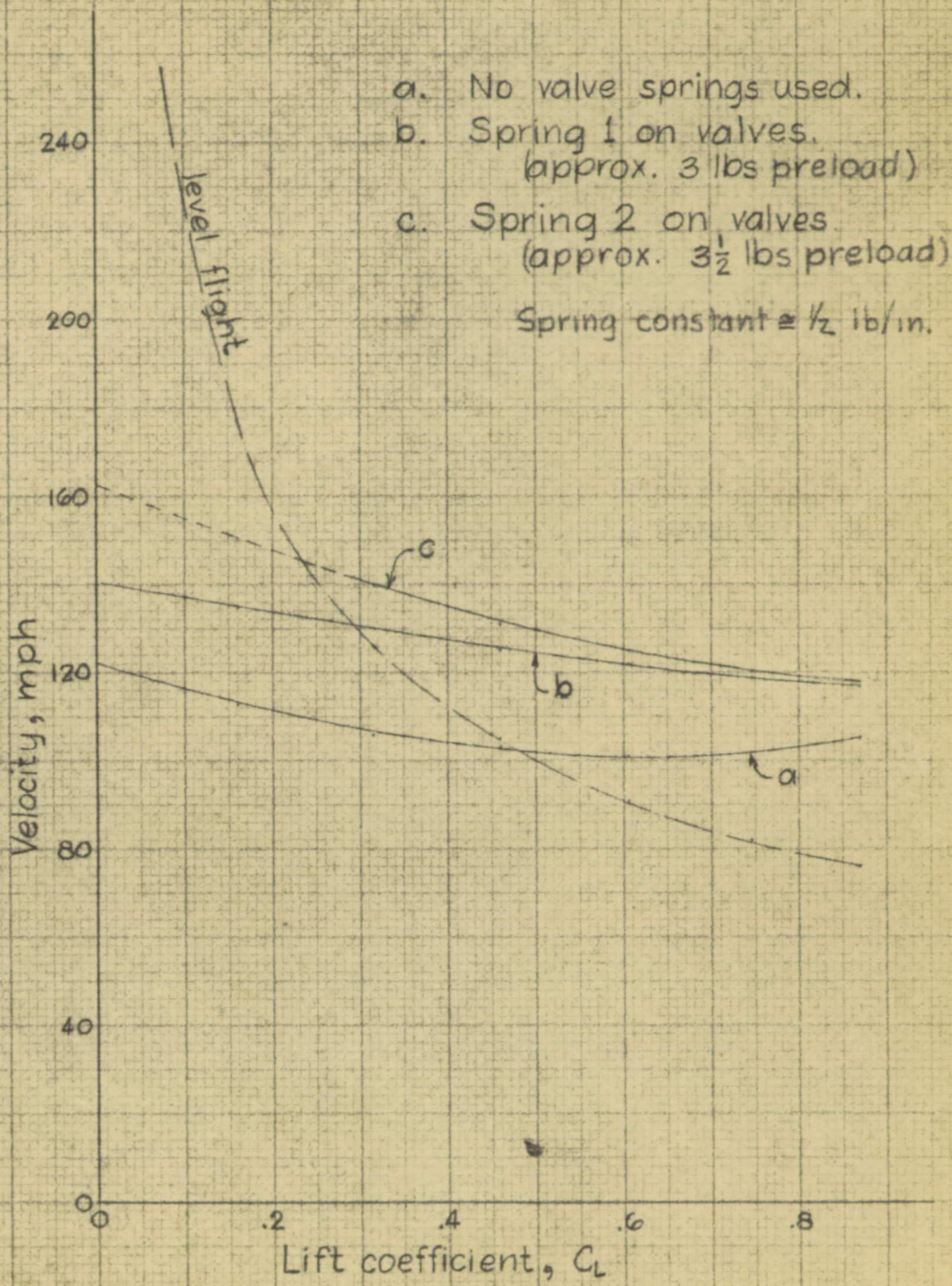


Figure 11.- Effect of aero boost valve springs on the minimum velocity at which chatter occurred. Northrop N9M-2 airplane.

[redacted]

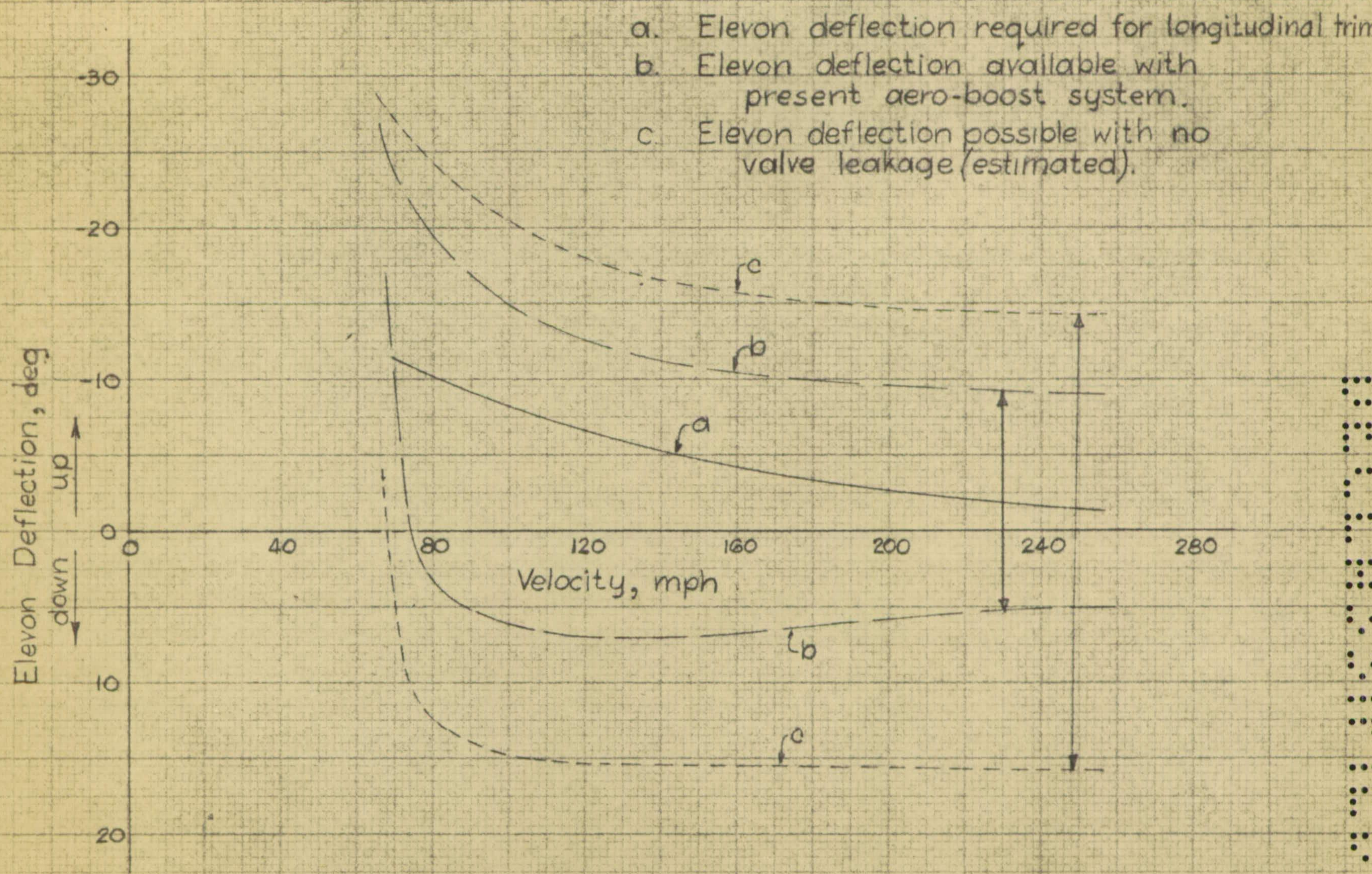


Figure 10.- Comparison of elevon deflection required for trim, elevon deflection available with present aero boost system, and elevon deflection possible with no valve leakage for Northrop N9M-2 airplane.

DECLASSIFIED