NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1173

FLIGHT MEASUREMENTS OF INTERNAL COCKPIT PRESSURES IN SEVERAL FIGHTER-TYPE AIRPLANES

By Edward C. B. Danforth, III and John P. Reeder

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

Washington
February 1947

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SUMMARY

Flight measurements of internal cockpit pressure have been made in several fighter-type airplanes equipped with either conventional or bubble canopies. Data are presented showing the variation in cockpit pressure with indicated airspeed and angle of sideslip for both the canopy-closed and the canopy-open conditions. The effect of admitting the cockpit ventilating air is shown for one airplane. The change in cockpit pressure accompanying a change in engine power is shown to be small. Data are presented showing the variation of cockpit pressure with normal acceleration at a constant value of free-stream impact pressure. At a given lift coefficient the cockpit pressure expressed as a fraction of free-stream impact pressure above free-stream static pressure is shown to be independent of normal acceleration. A method is outlined for predicting the cockpit pressure in accelerated flight from measurements made in unaccelerated flight.

INTRODUCTION

The need for a more accurate prediction of the loads on the cockpit canopies of service airplanes has been made evident by the occurrence of canopy failures in flight and difficulties encountered in opening and jettisoning the canopies. In order to predict the load on a canopy it is necessary to know the pressure distribution over the outer surface of the canopy and the internal pressure within the cockpit. The external pressure distribution may be readily determined from wind-tunnel tests of models or estimated by the method of reference 1. Cockpit pressure cannot ordinarily be so determined, because of the difficulty of estimating the magnitude of the leak areas that would be present in the canopy and cockpit of the proposed airplane.

Flight data on internal cockpit pressures have been collected for representative conventional and bubble canopies, and are presented herein as a part of a general program to investigate the pressure distribution on cockpit canopies in flight. The data are presented to indicate the magnitude and variation of the internal pressures that may be expected and are applicable to other airplanes whose configuration and cockpit leakage are similar to those tested. It is to be expected that airplanes with similar construction would have similar amounts of cockpit leakage. No evaluation of design criterions is made.

The data in the present paper would also be of interest in connection with carbon-monoxide studies and the problems of heating and cooling the cockpit.

SYMBOLS

C_L	airplane lift coefficient
p_i	internal static pressure under canopy, pounds per square foot
p_e	external static pressure over canopy, pounds per square foot
p_o	free-stream static pressure, pounds per square foot
q_c	free-stream impact pressure, pounds per square foot
$\frac{p_i - p_o}{q_c}$	internal pressure coefficient
$\frac{p_e - p_o}{q_c}$	external pressure coefficient
V_c	calibrated airspeed, miles per hour
β	angle of sideslip, degrees
g	acceleration due to gravity, feet per second per second

APPARATUS

Equipment installed for the present tests included a differential pressure indicator to measure the difference between cockpit pressure and free-stream static pressure and, for airplanes D and E, a yaw-angle indicator connected to a standard NACA yaw vane. The airspeed V_c and impact pressure q_c were obtained from the readings of the service airspeed indicators.

TESTS

The tests conducted on each airplane are summarized in table I. All data were obtained under steady conditions of flight and all pressures have been corrected for installation and head errors.

Since no altitude pressure measurements are available, all cockpit pressures in this report are presented as functions of the impact pressure q_c. Although the cockpit pressure may be more nearly a function of the dynamic pressure q, the error incurred through the use of q_c should be small.

RESULTS AND DISCUSSION

Effect of Canopy Shape

The pressure within the cockpit of an airplane in flight is dependent upon the leak areas through which air may flow into and out of the cockpit and the pressure drop across these leaks. In general, air enters the cockpit from some higher pressure region such as the tail-cone opening and leaves through leaks in and around the canopy to the lower pressure region surrounding the canopy.

The external pressure coefficient $\frac{p_e - p_o}{q_c}$ is dependent upon the size, shape, and angle of attack of the canopy and its location with respect to the pressure fields of the wing and fuselage. The higher and more abrupt the profile of the canopy, the greater the magnitude of the external pressure coefficient and the lower the pressure in the cockpit. Any leaks communicating with high negative pressure regions of the wing or fuselage will further reduce the cockpit pressure.

Side views of all airplanes discussed are shown in figure 1, and the general effect of canopy profile on internal cockpit pressure with canopy closed is indicated in figure 2. It is seen that those airplanes with low, flat canopy profiles, such as airplanes B and F, experience the least cockpit depression. The internal pressure coefficients $\frac{p_i - p_o}{q_c}$ for the high-speed range lie between -0.01 for airplane B and -0.17 for airplane A.

The shape of the canopy was not the only factor contributing to the low cockpit pressures measured in airplanes A and C. For airplane A, air flow through the cracks at the bottom of the doors to the low-pressure field of the wing caused an additional drop in cockpit pressure. The leak area around the canopy of airplane C was large in comparison with that for similar types of canopy considered in figure 2.

The pressures shown for airplane B are not quite comparable with the rest of the data in figure 2. It was not possible to shut off completely the ventilating air in this airplane; consequently, the cockpit was rammed slightly.

With the exception of the data for airplanes D and E, all data presented herein were obtained from flight measurements made over an extended period of time as the airplanes became available. Errors due to slightly open ventilators, therefore, may be present for airplanes other than airplane B. From inspection of the data, however, it appears that if such errors are present they are much smaller than that for airplane B.

Effect of Opening Canopy

Opening the windows or canopy of an airplane increases the ease with which air may flow out of the cockpit, and thus lowers the cockpit pressure still further for a given value of q_c or increases the rate of depression with speed. The variation of cockpit pressure with q_c with canopy open is shown for several airplanes in figure 3. The variation with canopy closed is included on each figure for comparison.

The drop in cockpit pressure caused by opening the canopy amounted to about $0.17q_c$ for airplane A, about $0.22q_c$ for airplanes B and C, and about $0.28q_c$ for airplanes D and E.

For airplanes D and E the cockpit-pressure pickup was attached directly to the inside of the canopy so that, with the canopy closed, the pickup was just above the pilot's head. Thus the indicated pressure was at all times representative of the internal load on the canopy. For the other airplanes the pressure pickups were attached to the upper right-hand part of the instrument panel. The data presented for airplane C with canopy open (fig. 3(c)) are subject to question, since with a sliding canopy of this type (fig. 1(c)) the pressure in the cockpit may not be equal to the internal pressure acting on the canopy. No question of this nature is present in the data for airplanes A or B since the canopies of those airplanes are equipped with windows and are not the sliding type.

Effect of Sideslip

In a sideslip, the asymmetrical flow over the canopy causes the external pressure coefficient to become more negative and therefore causes the internal cockpit pressure to decrease still more rapidly with q_c. At a given speed the cockpit pressure may be expected to decrease as the angle of sideslip is increased until the canopy stalls.

The effect of sideslip on cockpit pressure is shown in figures 4(a) and 5(b) for airplanes D and E, respectively. With canopy closed, at a given airspeed, the cockpit pressure is seen to decrease still further with angle of sideslip. For airplane D at 250 miles per hour with canopy closed, 20° right sideslip caused the cockpit pressure to decrease by 18 pounds per square foot. With canopy open, at a given airspeed, the cockpit pressure increases with angle of sideslip. In this case the air comes directly into the cockpit and has a ramming effect. At 200 miles per hour with canopy open, 10° left sideslip caused an increase in cockpit pressure of about 35 pounds per square foot.

In figures 4(b) and 5(b) the data have been replotted against q_c for constant angles of sideslip. With canopy closed, the rate of change of cockpit pressure with q_c increases with angle of sideslip. With canopy open, the effect of sideslip at a given speed is to increase the cockpit pressure. The over-all effect of increasing the speed at a constant angle of sideslip, however, is to decrease the cockpit pressure.

It should be noted that for airplane D all sideslip data for the canopy-closed condition were measured with the ventilating air full on. Data to be presented in the following section indicate that, with canopy closed, the ramming action of the ventilating air increased the cockpit pressure by approximately $0.07q_c$. With the ventilating air off, the cockpit temperature was unbearable and precluded obtaining data for this condition. No such difficulty was encountered with airplane E. The magnitude of the pressures obtained in sideslip in the airplanes D and E are thus not directly comparable, but it is felt that the change in cockpit pressure per degree of sideslip angle at any given speed should be comparable. The cockpit pressure appears to decrease slightly more rapidly for airplane E than for airplane D although it is difficult to reach any definite conclusions because of the limited amount of data for airplane E.

Effect of Ventilating Air

Measurements were made in airplane D as an example of the magnitude of the pressure changes within the cockpit with the ventilating air on and off. In spite of the high cockpit temperatures measurements could be obtained in straight flight by turning the ventilating air off just long enough to read the cockpit-pressure indicator. These data are presented in figure 6. The ventilating air has the effect of ramming the cockpit and for this case the cockpit pressures were increased by approximately $0.07q_c$ throughout the speed range tested.

Effect of Power

Measurements of cockpit pressure in the power-off condition have been made in airplanes A, B, and C and are presented in figures 7(a), 7(b), and 7(c), respectively. The cockpit pressure with power off was about 5 pounds per square foot higher than with power on because of the lowered velocity over the canopy in the absence of the propeller slipstream. The data for airplane B (fig. 7(b)) are unusual in that, at high speeds, lower cockpit pressures were obtained with power off than with power on. This result is due to the slightly open cockpit ventilator. The ventilating air, coming from the entrance of the radiator duct, would be at a lower pressure with power off than with power on. The consequent reduction in flow of the ventilating air was apparently enough to more than compensate for the reduced velocity over the canopy.

Effect of Normal Acceleration

For unaccelerated flight it was found convenient to plot the cockpit pressure differential $p_1 - p_o$ against q_c, since, except for the effect of compressibility, q_c is a function of the attitude of the airplane. This method of plotting the data can be extended to accelerated flight by retaining the normal acceleration as a parameter.

Measurements of cockpit pressure have been made in airplane B in turns under normal accelerations of 2 g and 3 g. These data are presented in figure 8(a). The cockpit pressure at a constant value of q_c is seen to increase with normal acceleration at a rate of about 5 pounds per square foot per g because of the increasing angle of attack of the airplane. In figure 8(b) these data have been replotted as $\frac{p_i - p_o}{q_c}$ against C_L and are thus independent of the normal acceleration.

The cockpit pressure in accelerated flight can be obtained from measurements made in unaccelerated flight. Since $\frac{p_i - p_o}{q_c}$ is solely a function of C_L, it is necessary only to calculate the q_c corresponding to a given value of C_L in accelerated flight and multiply it by the value of $\frac{p_i - p_o}{q_c}$ corresponding to the same value of C_L in unaccelerated flight.

These calculations were made for airplanes A, D, and E in the canopy-closed condition, and the results obtained have been plotted in figures 9, 10, and 11, respectively. Airplane E, which showed the largest variation of $\frac{p_i - p_o}{q_c}$ with C_L, has, naturally, the greatest change in cockpit pressure with normal acceleration at a constant value of q_c (fig. 11). The effect of acceleration is not so great for airplane D (fig. 10) as for airplane E. It will be noted that the cockpit pressures decrease with normal acceleration for airplane A at values of q_c below 240 lb /sq ft (fig. 9(b)) and the slope of the curve of $\frac{p_i - p_o}{q_c}$ against C_L changes sign. This effect is probably the result of excessive leakage of air from the cockpit to the low-pressure region of the wing-fuselage junction at the higher lift coefficients.

SUMMARY OF RESULTS

An analysis of internal cockpit pressure measurements for six fighter-type airplanes showed the pressure within the cockpit to be almost invariably negative with respect to free-stream static pressure. As in the case of airplanes B and D a small positive cockpit pressure may be expected at low speeds with ventilating air on. In straight flight with canopy closed the cockpit pressures for all airplanes tested ranged between the pressures measured in airplanes A and B. The internal pressure coefficient was almost zero in the case of airplane B but was as great as -0.17 for airplane A.

Opening the canopy in straight flight always caused a further drop in cockpit pressure. For airplane A this drop amounted to about $0.17q_c$ (where q_c is free-stream impact pressure), for airplanes B and C to about $0.22q_c$, and for airplanes D and E to about $0.28q_c$.

The effect of sideslip was to decrease further the cockpit pressure with canopy closed and to increase it with canopy open. For airplane D at 250 miles per hour with canopy closed, 20° right sideslip caused the cockpit pressure to decrease by 18 pounds per square foot. At 200 miles per hour with canopy open, 10° left sideslip caused an increase in cockpit pressure of about 35 pounds per square foot.

The effect of admitting the cockpit ventilating air is to increase the cockpit pressure and, for the case of airplane D, amounted to about $0.07q_c$ throughout the speed range tested.

For the airplanes tested, the cockpit pressure in the power-off condition was found to be about 5 pounds per square foot higher than that measured with power on at corresponding airspeeds.

The effect of normal acceleration on cockpit pressure was found to be about 5 pounds per square foot per g at a constant value of q_c for airplane B. The internal pressure coefficient when plotted against the airplane lift coefficient is independent of the normal acceleration.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., July 26, 1946.

REFERENCE

1. Wright, Ray H.: Estimation of Pressures on Cockpit Canopies, Gun Turrets, Blisters, and Similar Protuberances. NACA ACR No. L4E10, 1944.

TABLE I.- AIRPLANES TESTED AND TEST CONDITIONS

Conditions tested / Airplane	Canopy closed	Canopy open	Sideslips; canopy closed and open	Ventilating air on and off; canopy closed	Power on and off	Effect of normal acceleration
A	x	x			x	
B	x	x			x	x
C	x	x			x	
D	x	x	x	x		
E	x	x	x			
F	x					

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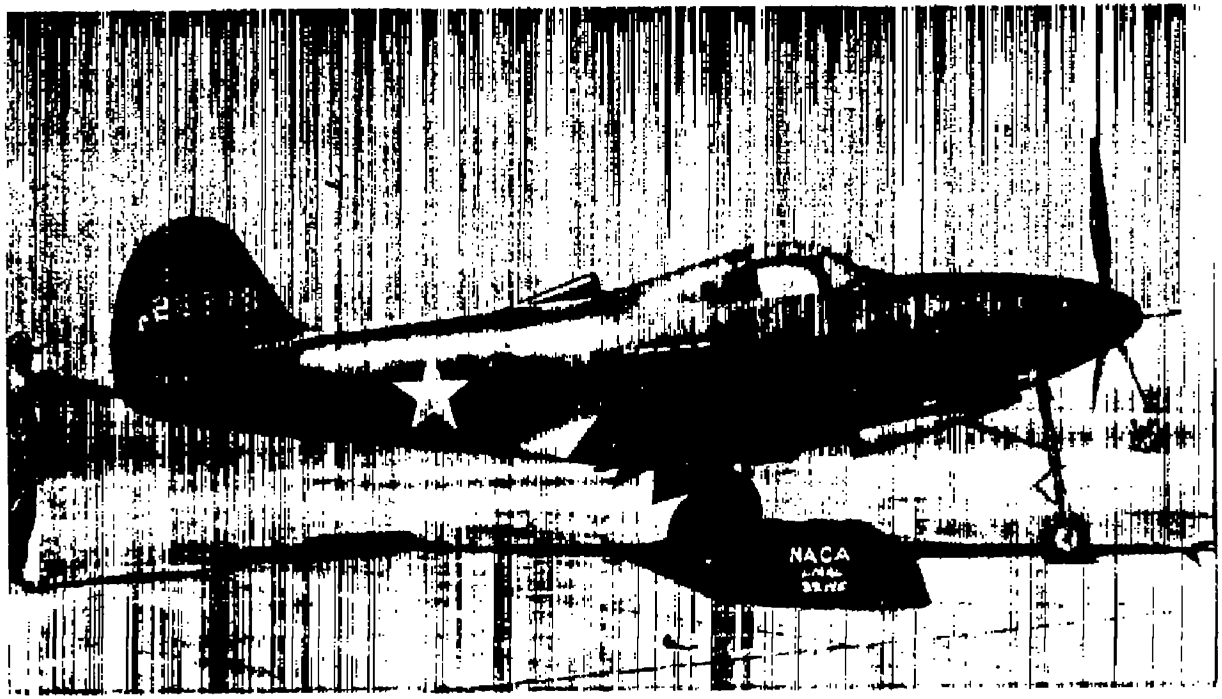
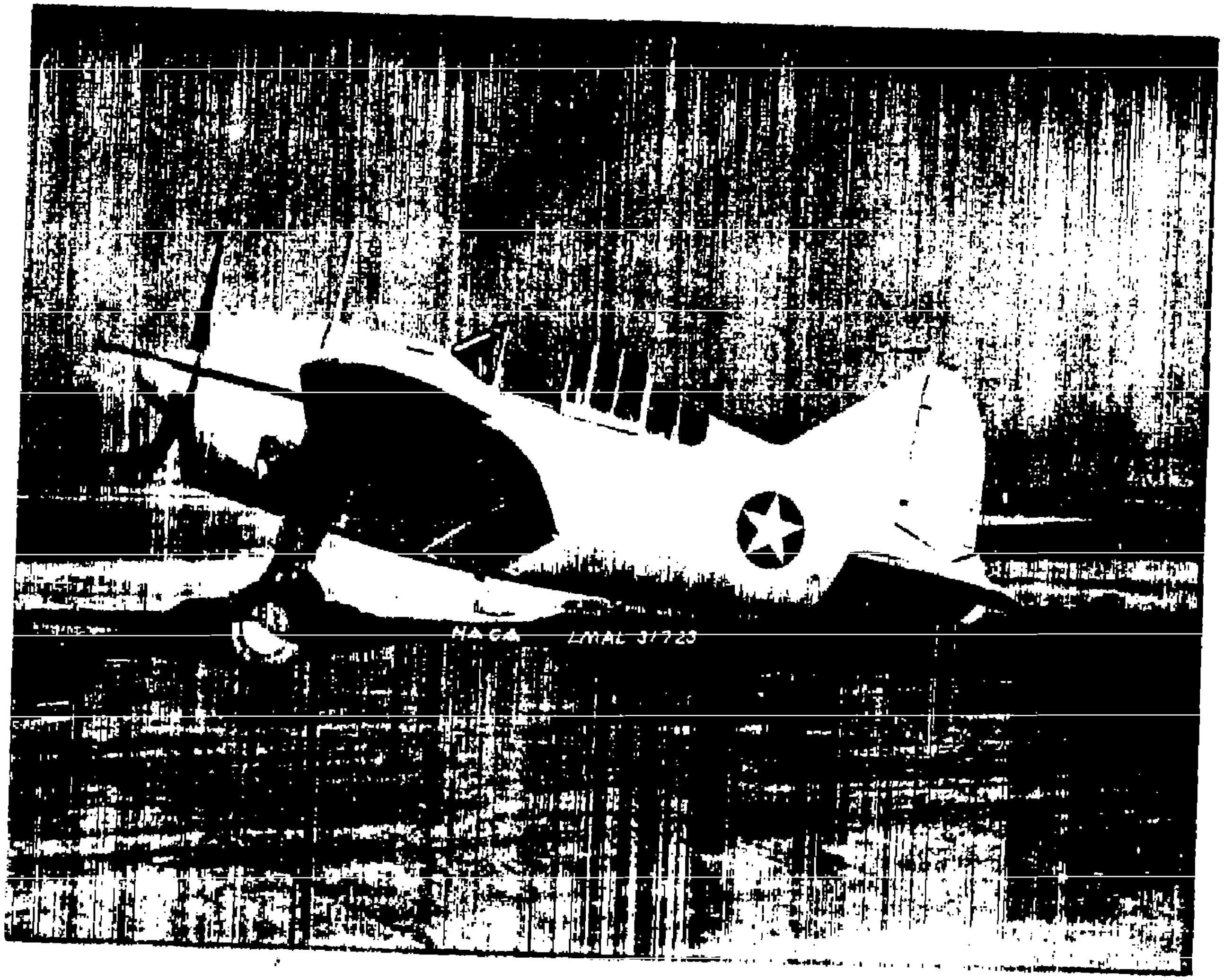


(a) Airplane A.

Figure 1.- Side views of test airplanes.

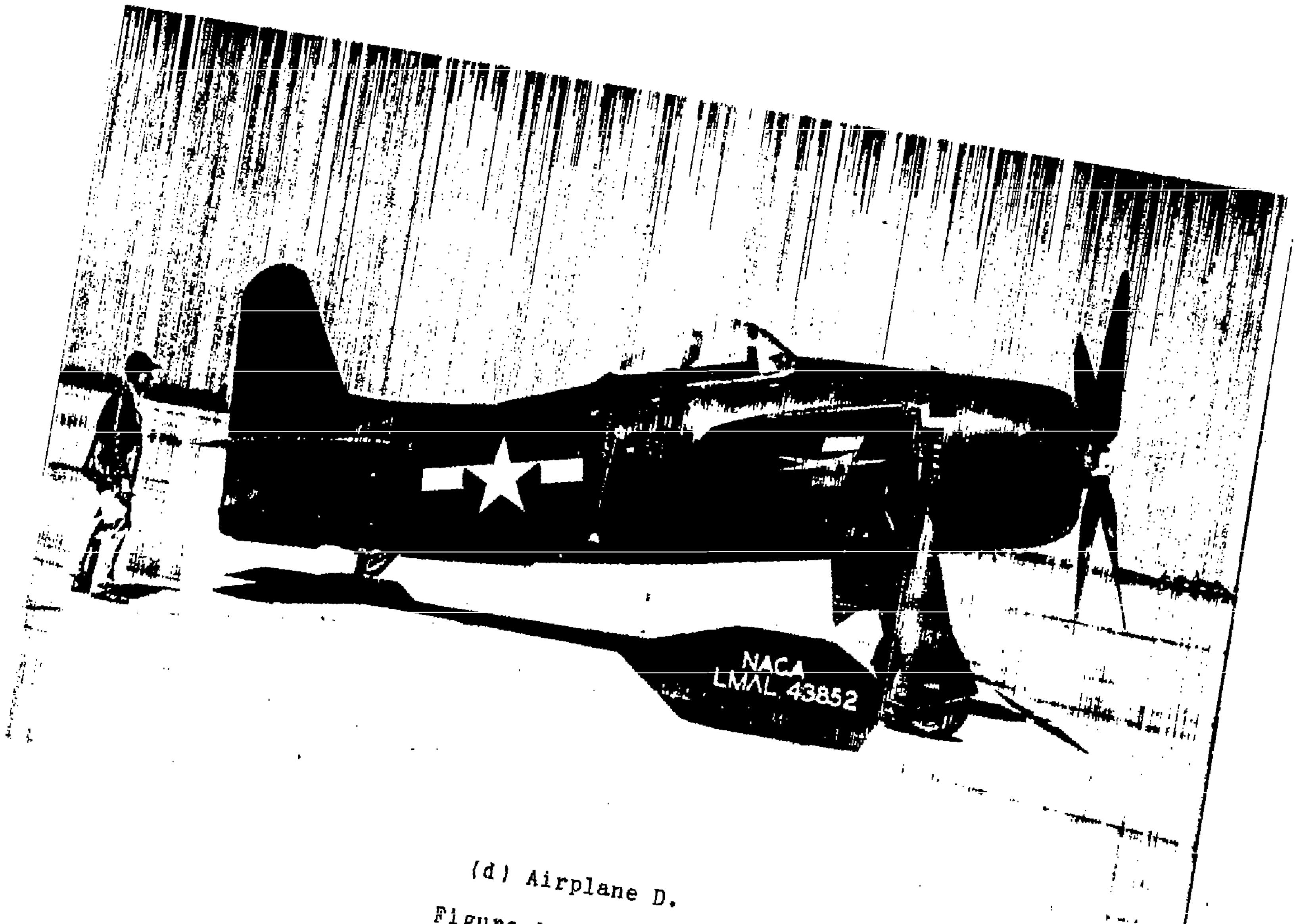
(b) Airplane B.

Figure 1.- Continued.



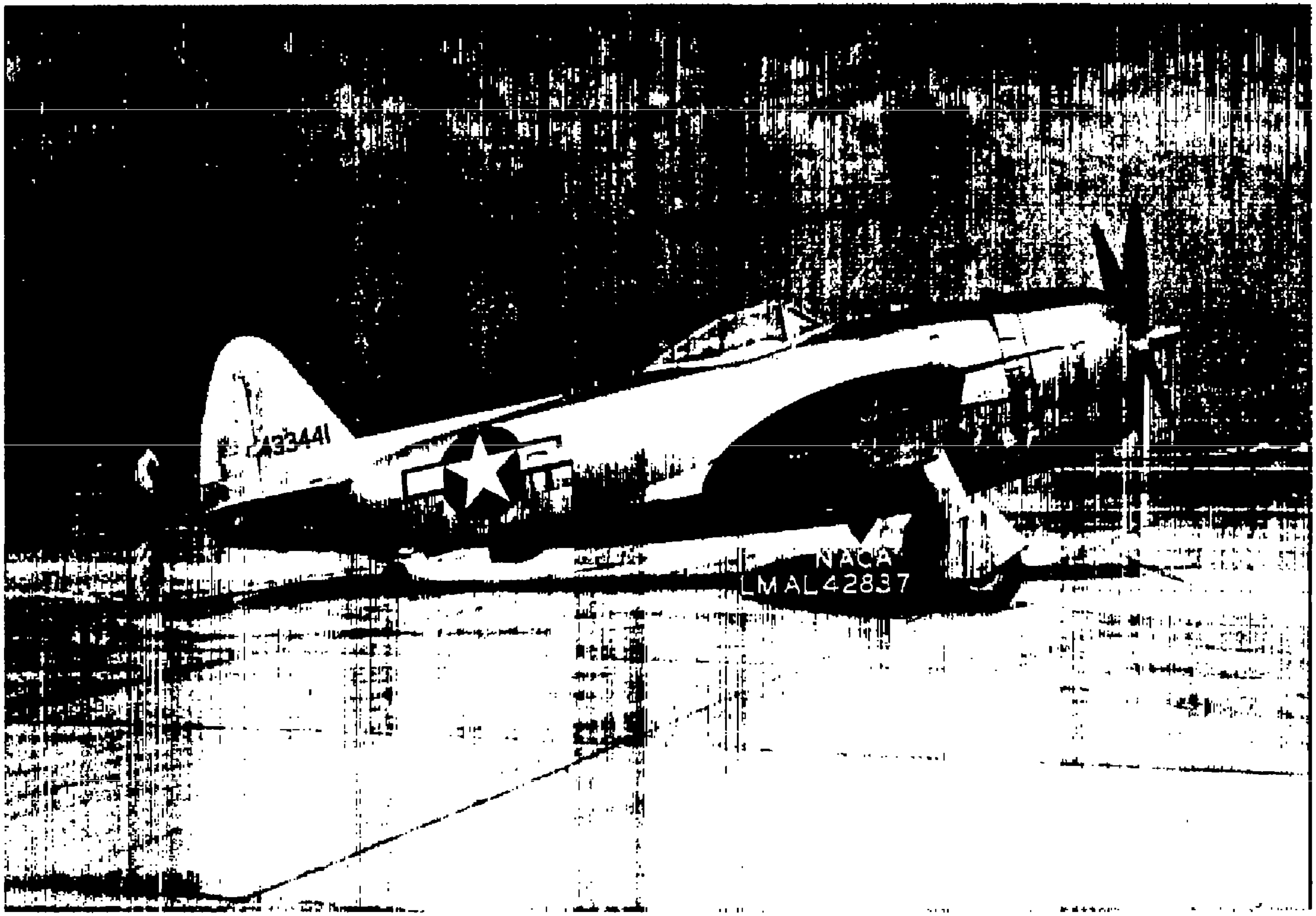
(c) Airplane C.

Figure 1.- Continued.



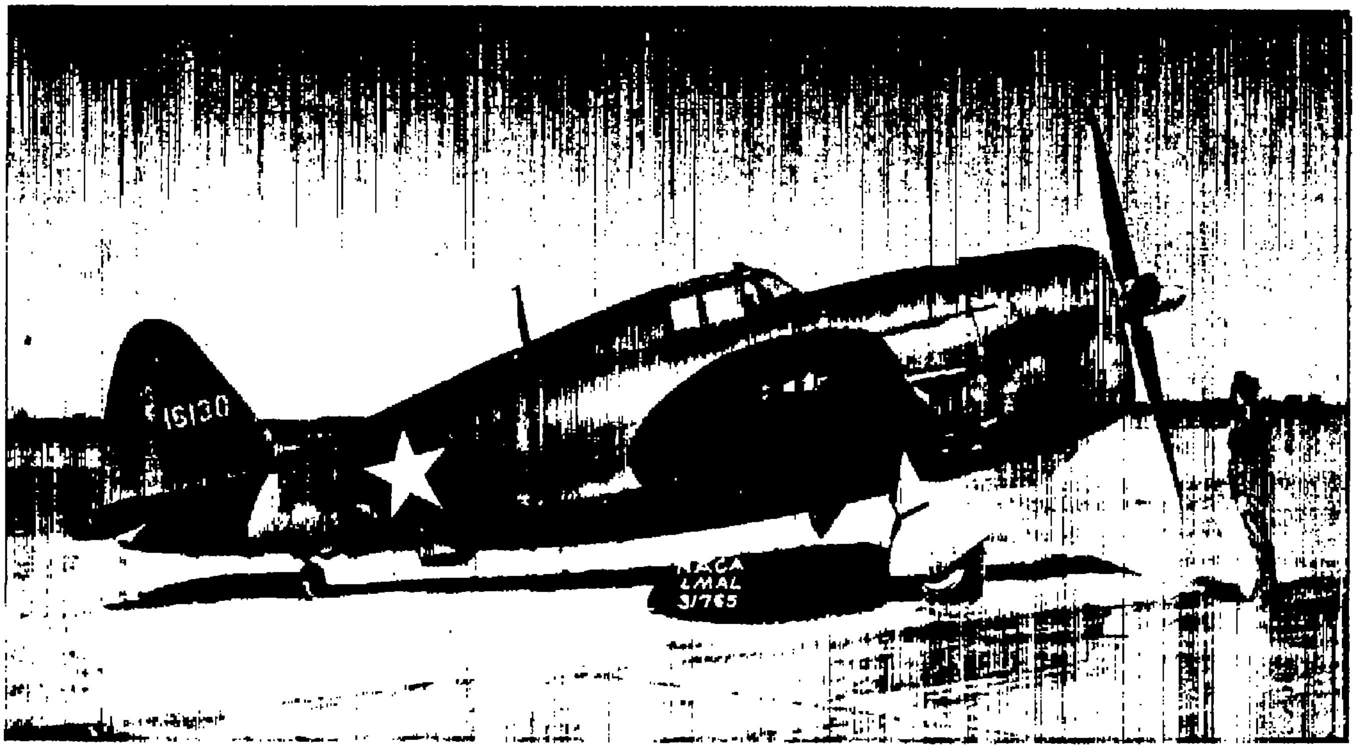
(d) Airplane D.

Figure 1.- Continued.



(e) Airplane E.

Figure 1.- Continued.



(f) Airplane F.

Figure 1. Concluded.

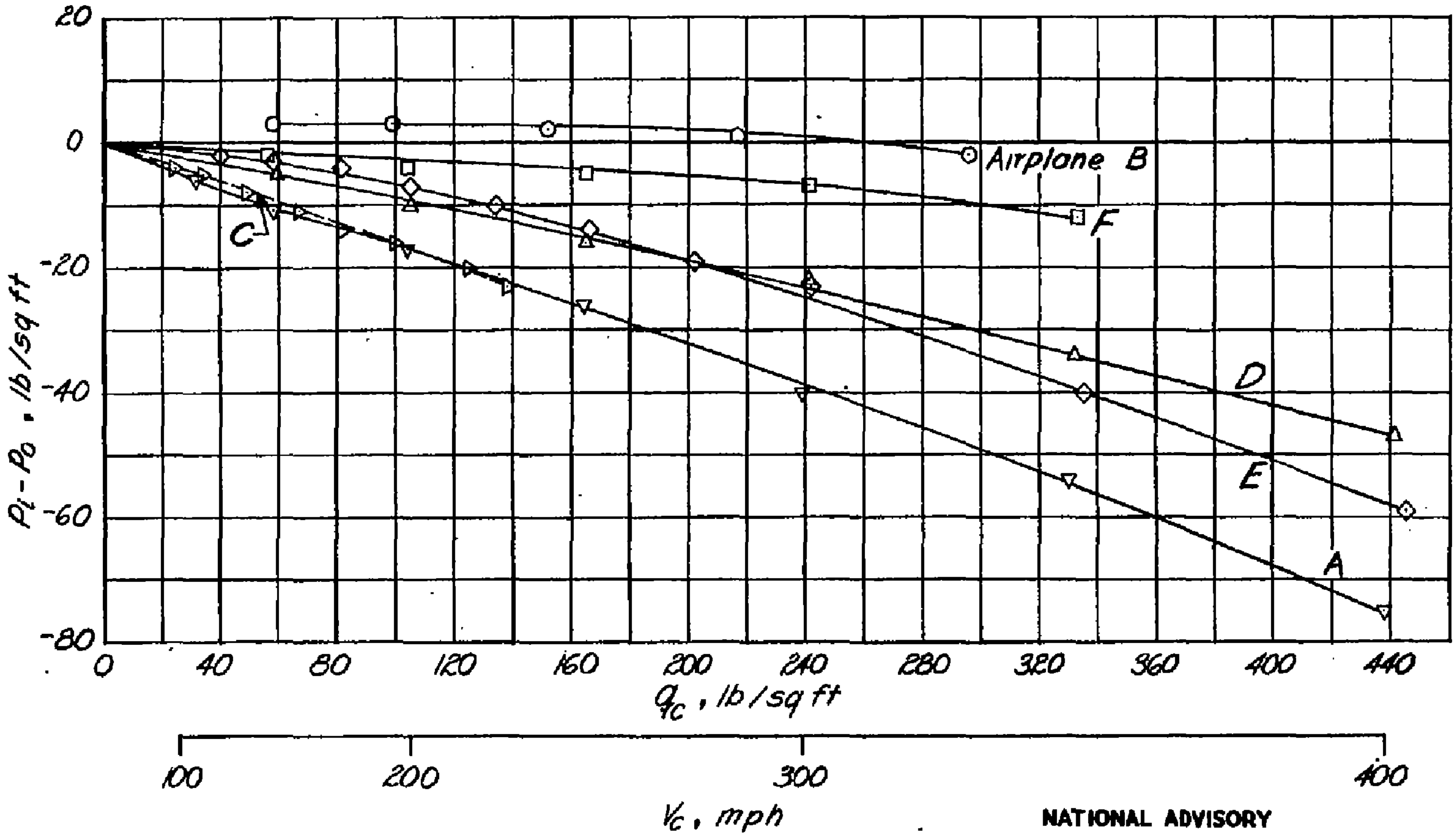


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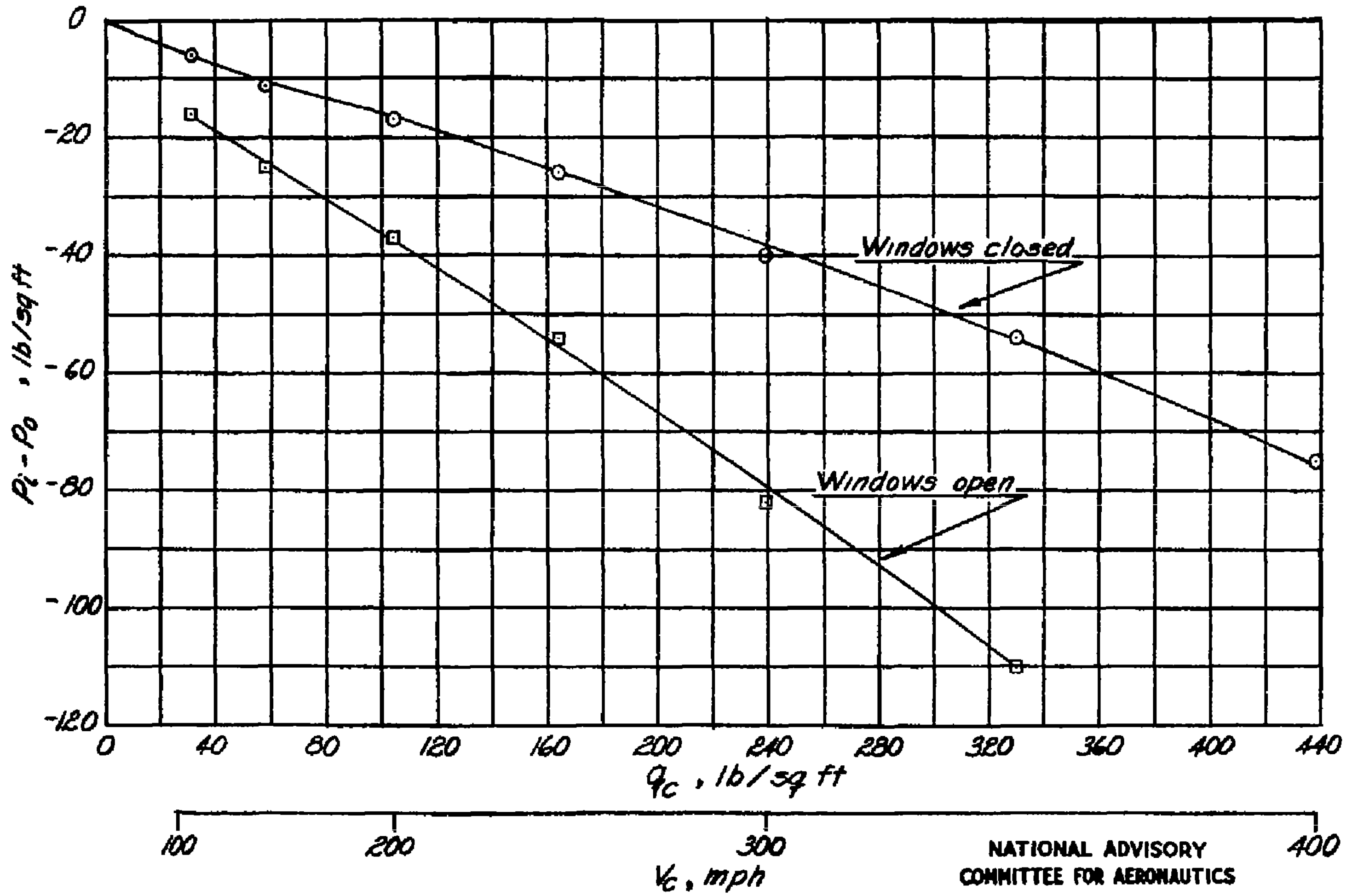
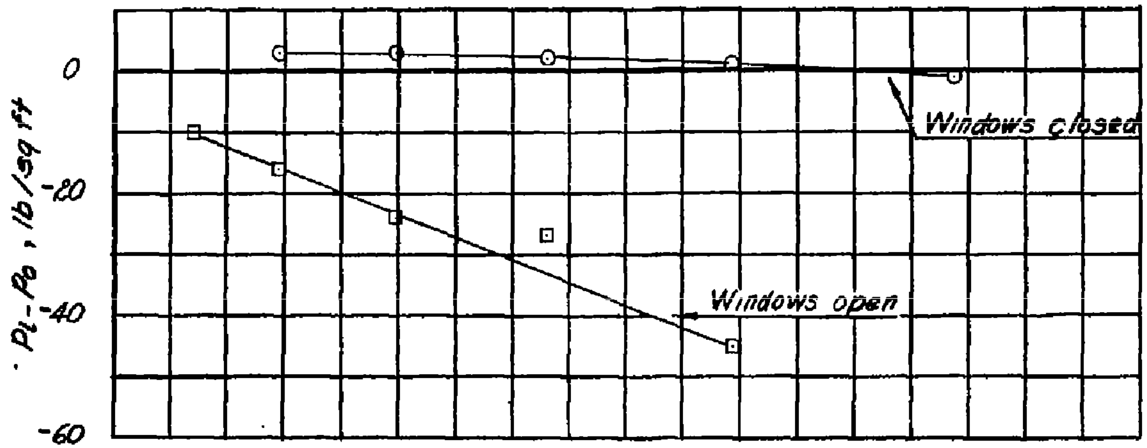
Figure 2.- Comparison of cockpit pressures with canopy closed and power on for several airplanes showing the variation of cockpit pressure with shape of canopy. Cockpit ventilator slightly open for airplane B.

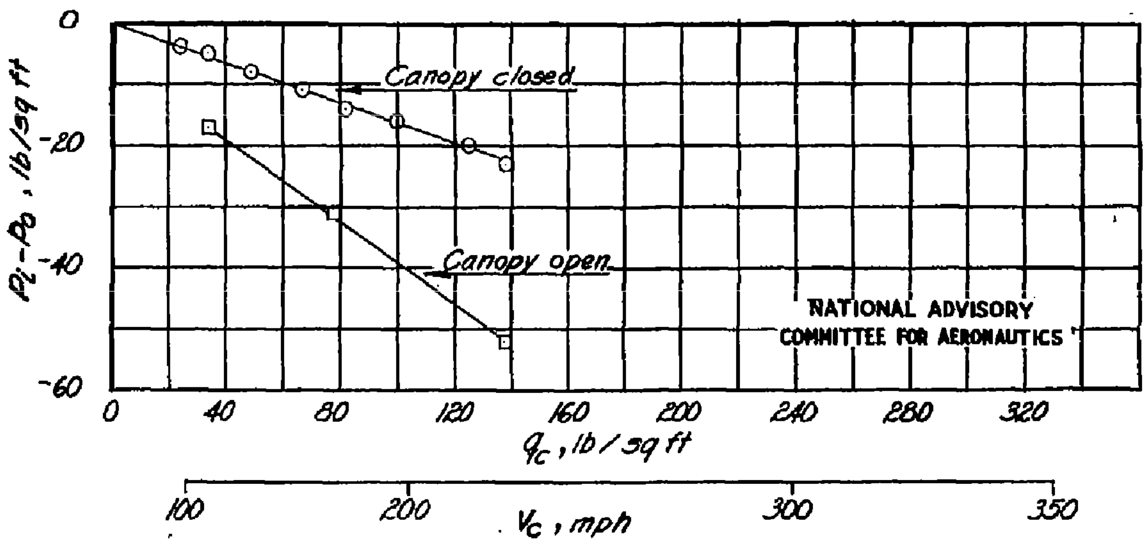


(a) Airplane A.

Figure 3.- Variation of cockpit pressure with q_c with canopy closed and canopy open. Power on.

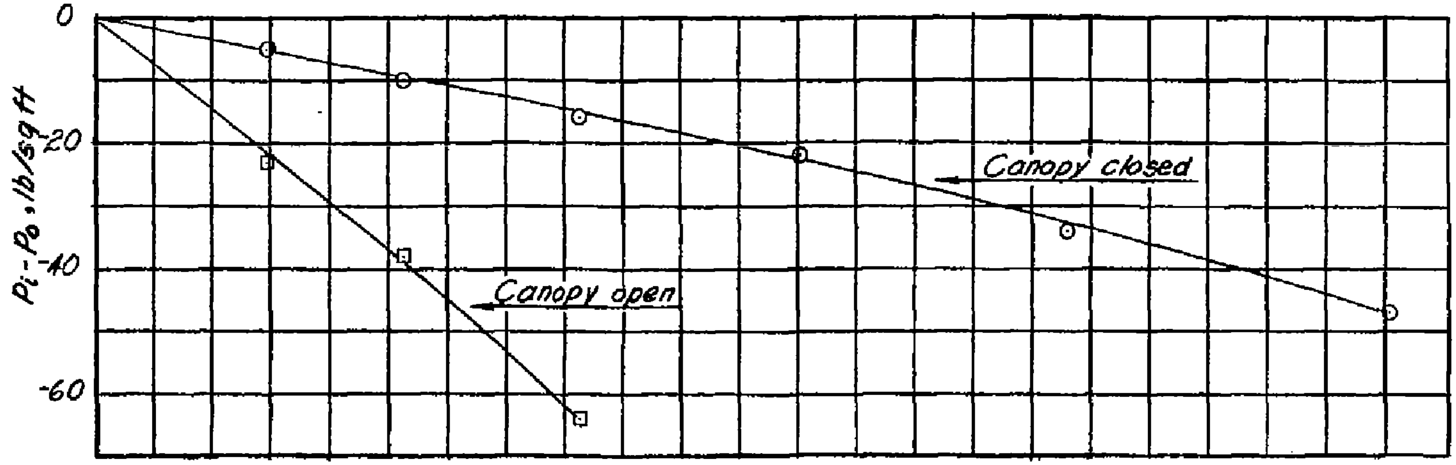


(b) Airplane B. Cockpit ventilator slightly open.

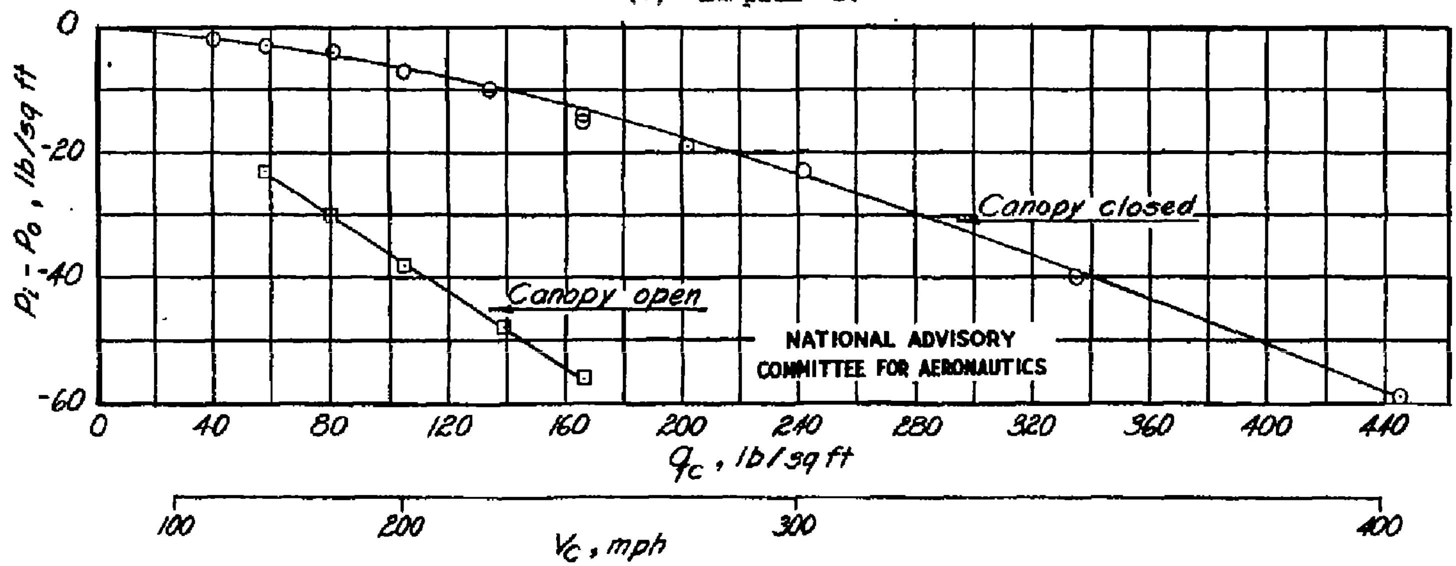


(c) Airplane C.

Figure 3.- Continued.

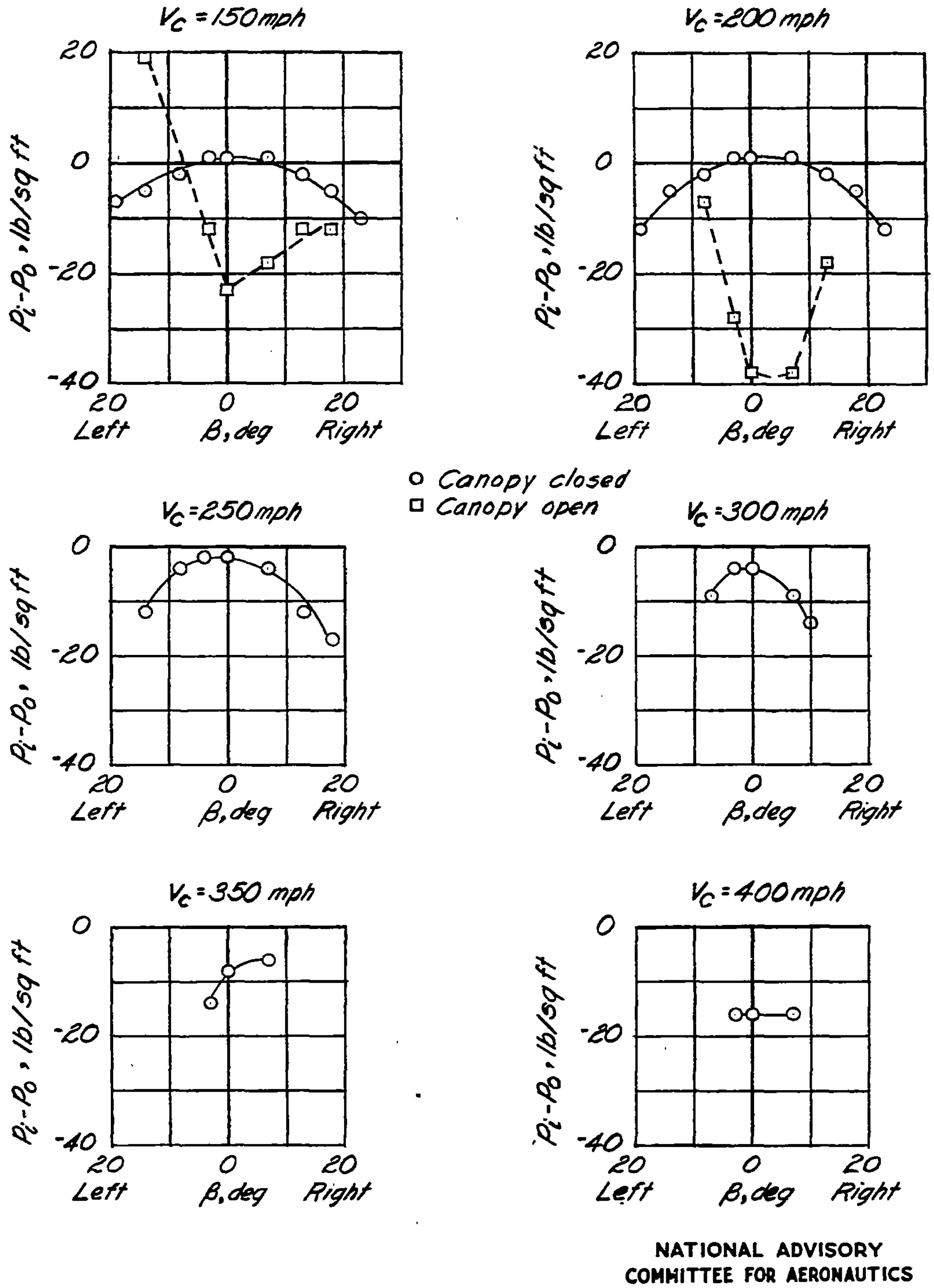


(d) Airplane D.

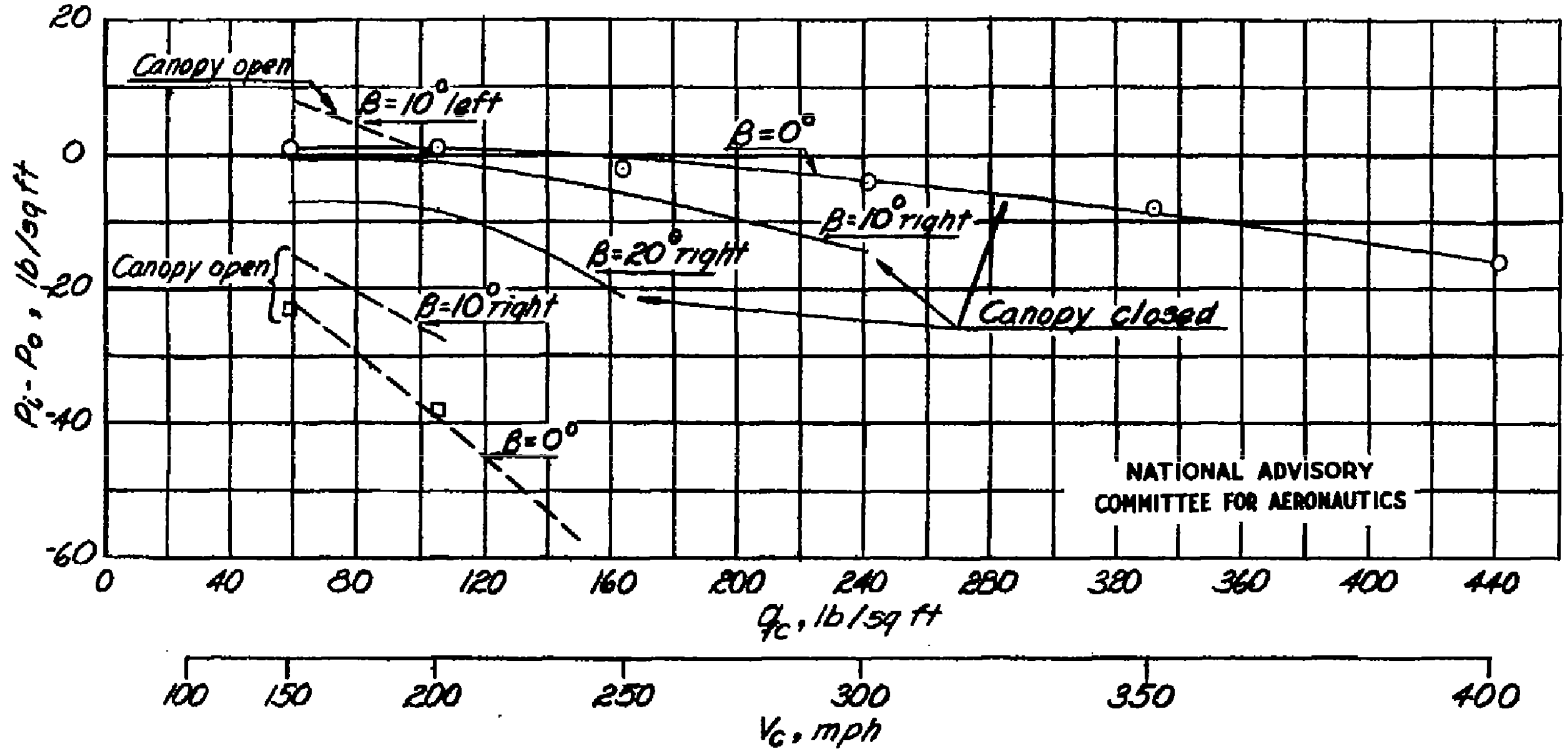


(e) Airplane E.

Figure 3.- Concluded.

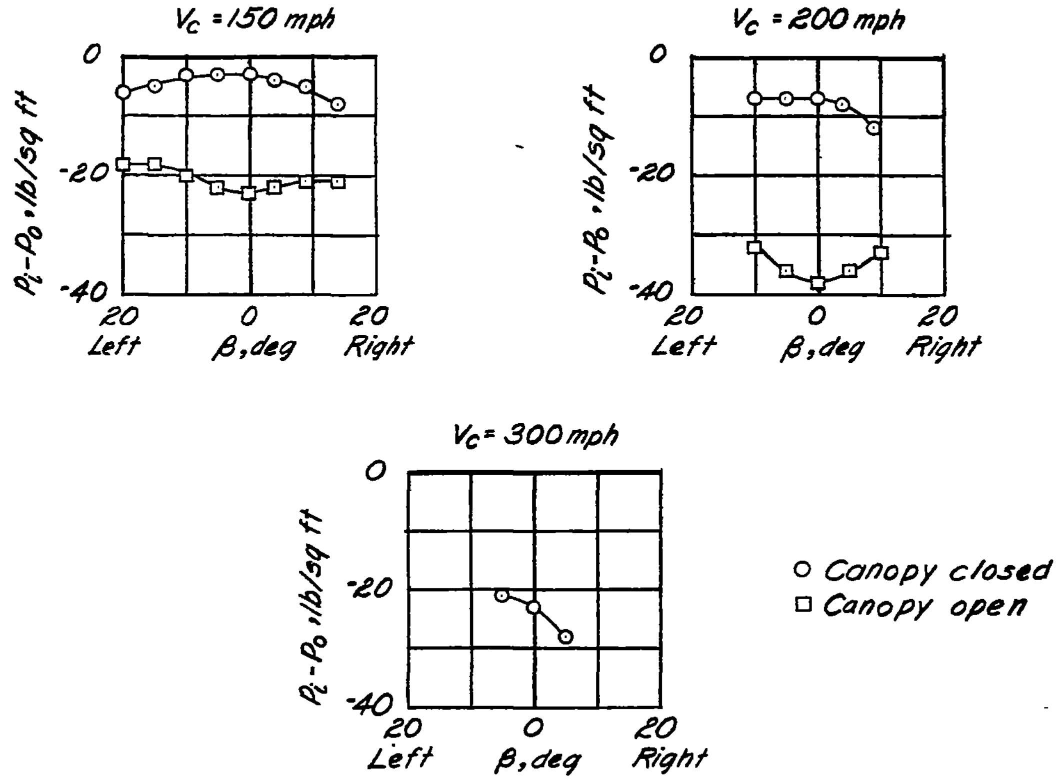


(a) Variation with angle of sideslip at constant calibrated airspeed.
Figure 4.- Effect of sideslip on cockpit pressure for airplane D. Ventilating air full on; power on.

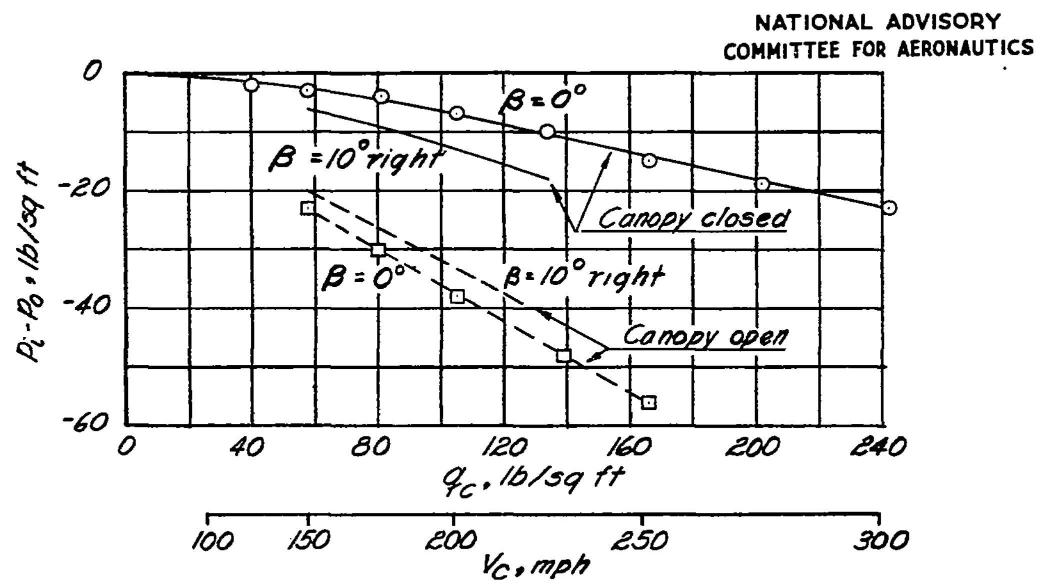


(b) Variation with q_c at constant angles of sideslip.

Figure 4.- Concluded.



(a) Variation with angle of sideslip at constant calibrated airspeed.



(b) Variation with q_c at constant angle of sideslip.

Figure 5.- Effect of sideslip on cockpit pressure for airplane E. Ventilating air off; power on.

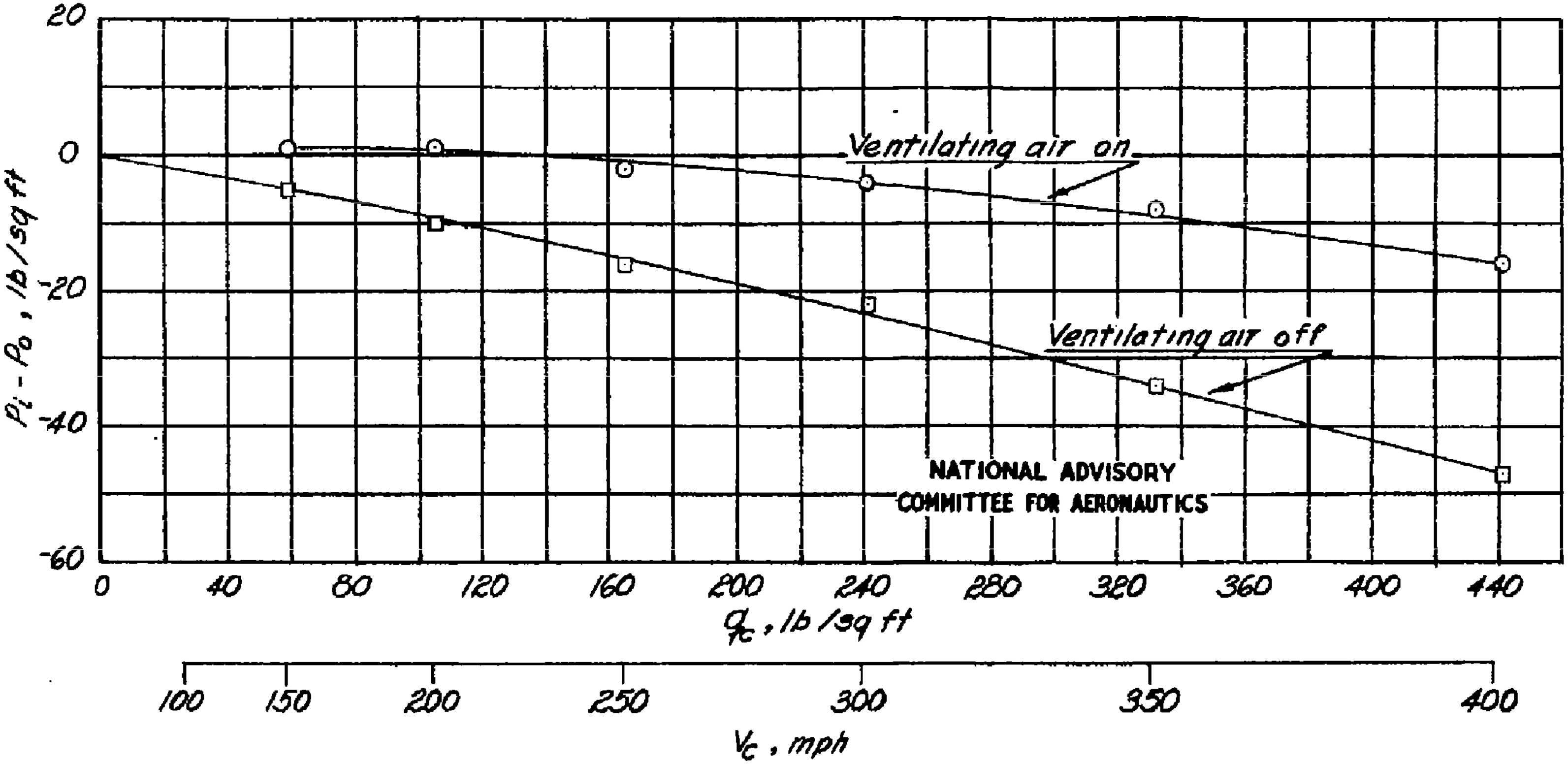
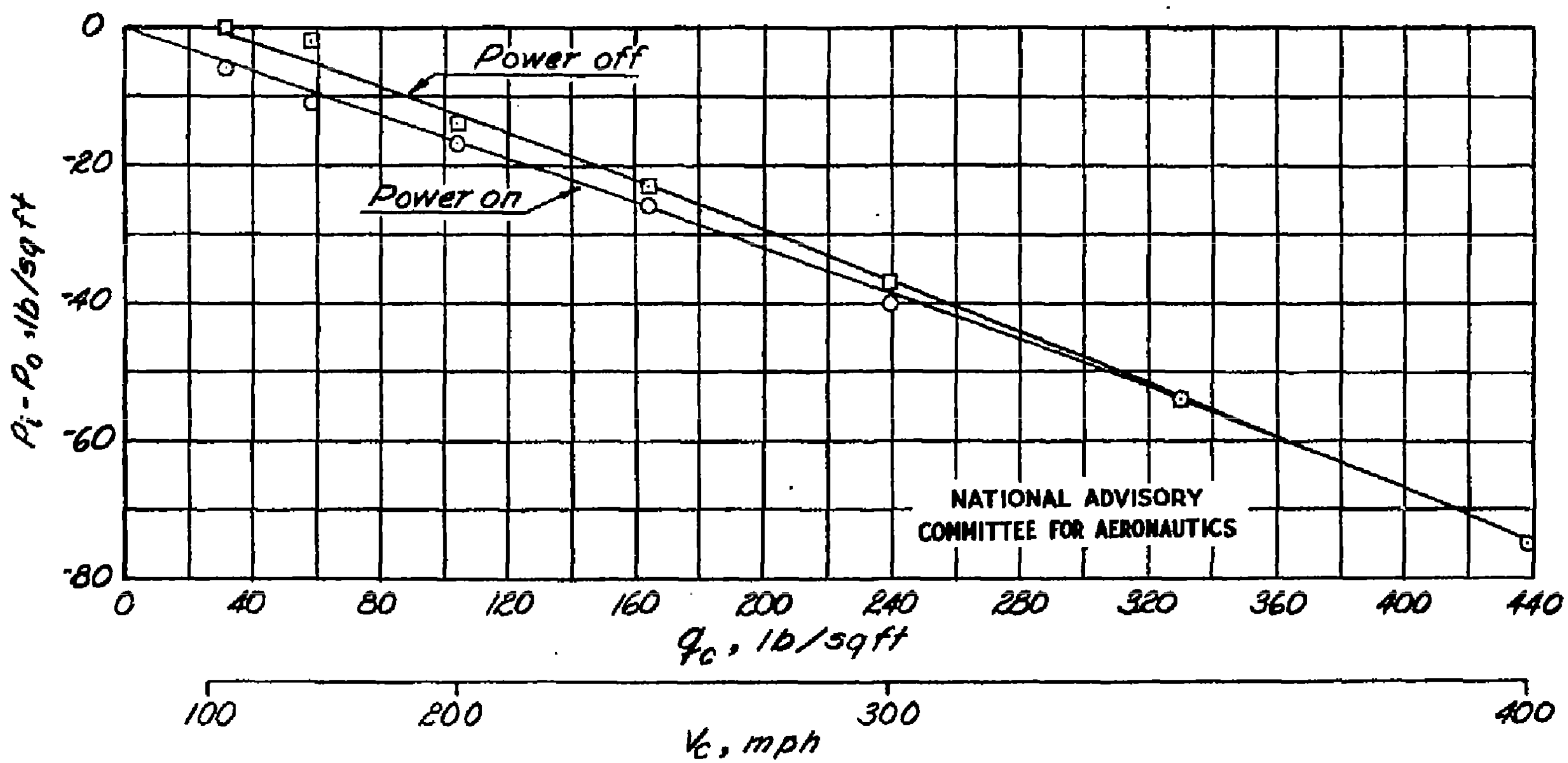
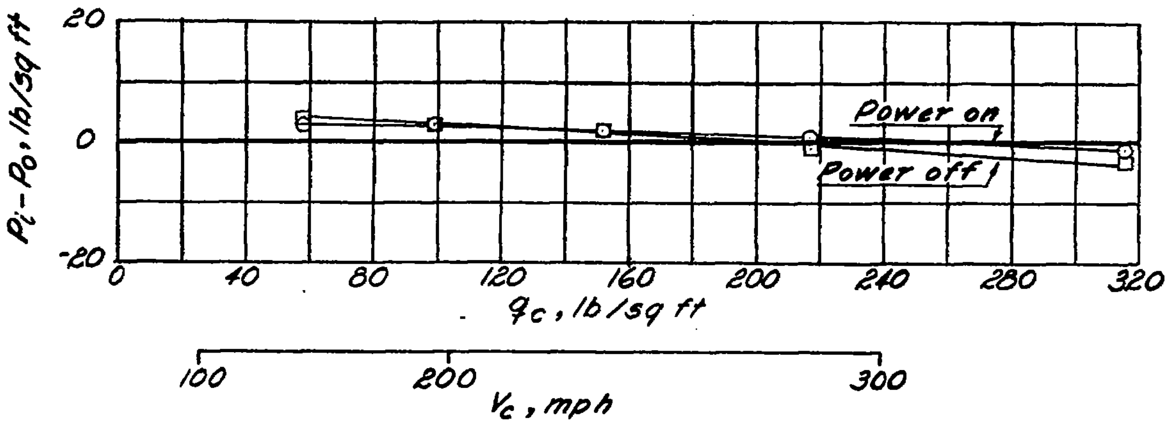


Figure 6.- Effect on cockpit pressure of admitting ventilating air in airplane D. Power on.

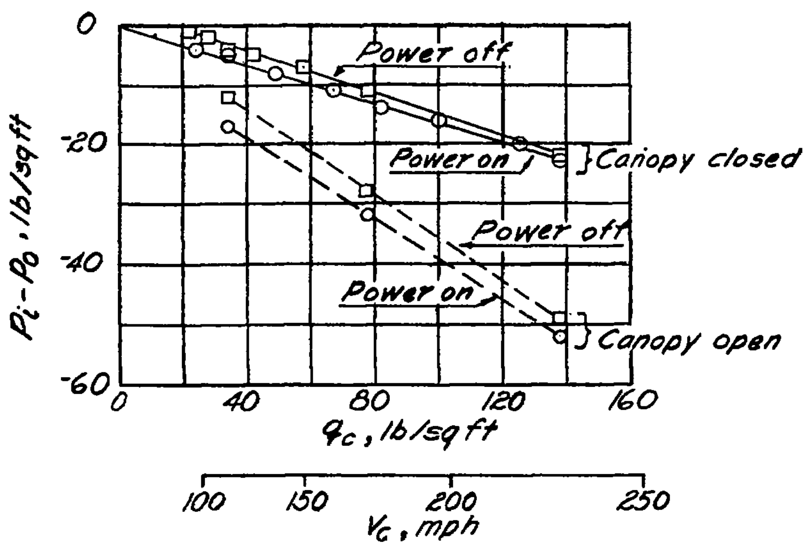


(a) Airplane A; canopy closed.

Figure 7.- Effect of engine power on cockpit pressure.



(b) Airplane B; canopy closed.



(c) Airplane C.

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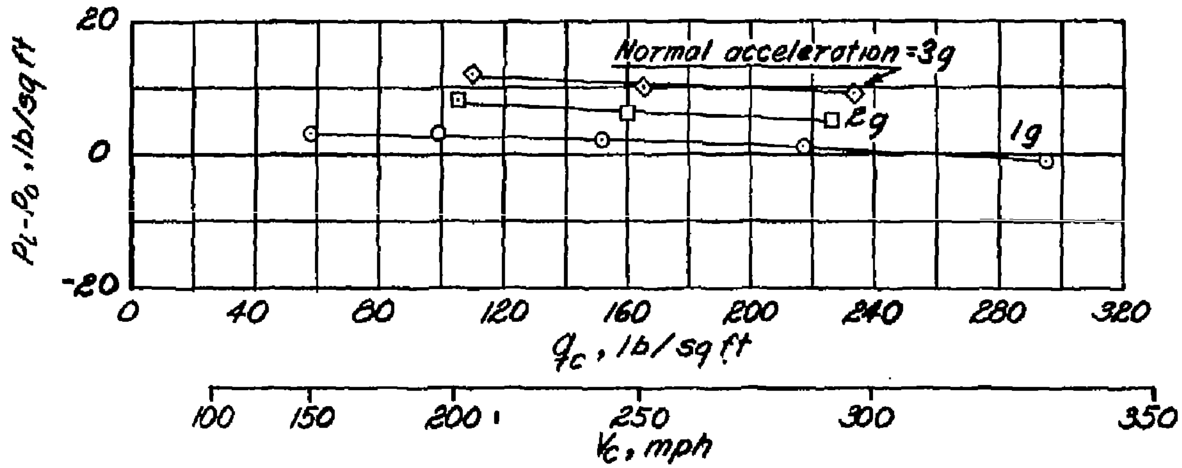
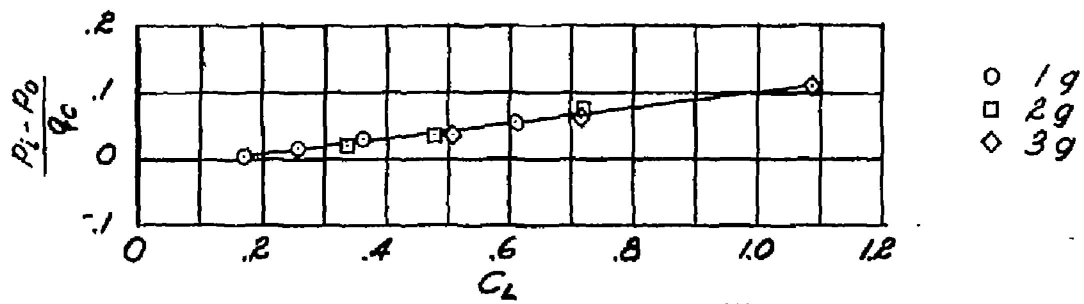
Figure 7.- Concluded.



(a) Variation of $p_i - p_o$ with q_c and normal acceleration.



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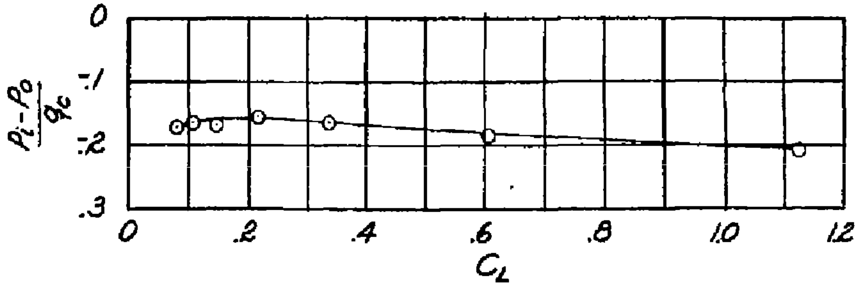
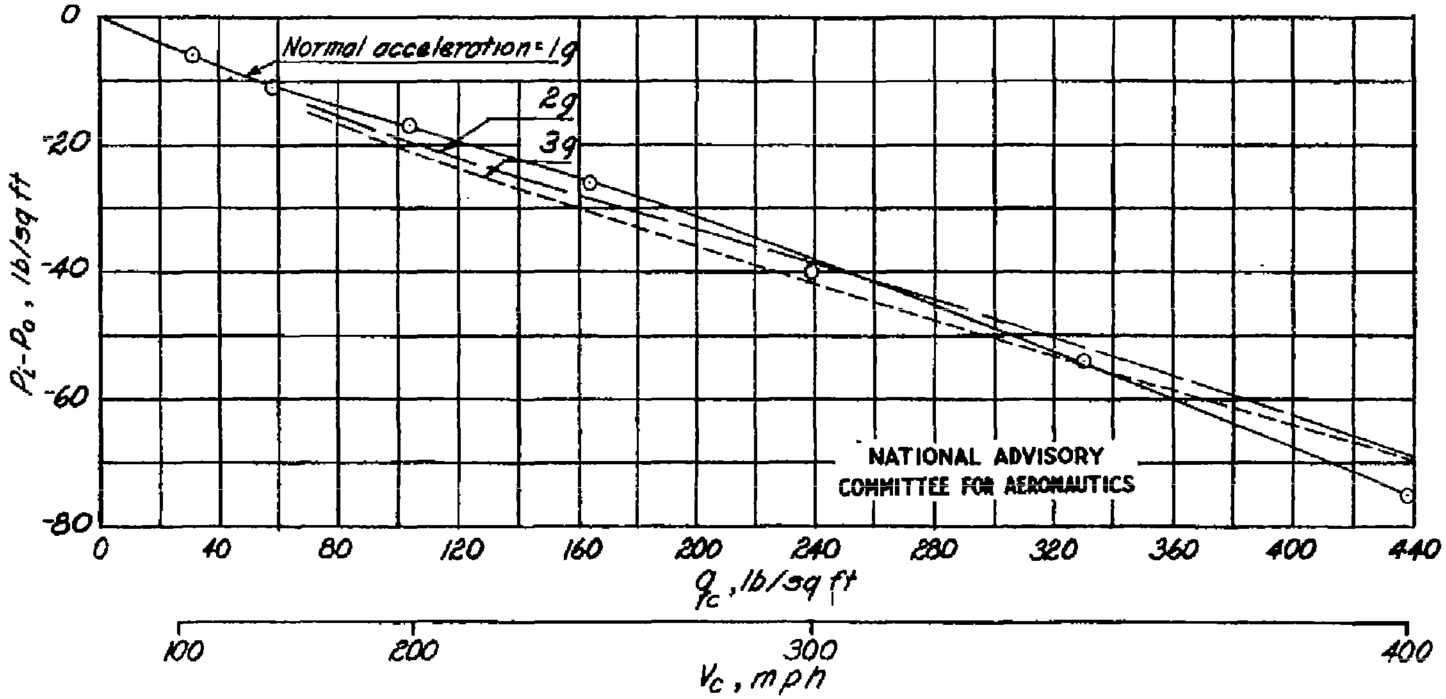
(b) Variation of $\frac{p_i - p_o}{q_c}$ with C_L. Same data as for figure 8(a).

Figure 8.- Effect of normal acceleration on cockpit pressure for airplane B with canopy closed, power on, and cockpit ventilator slightly open.

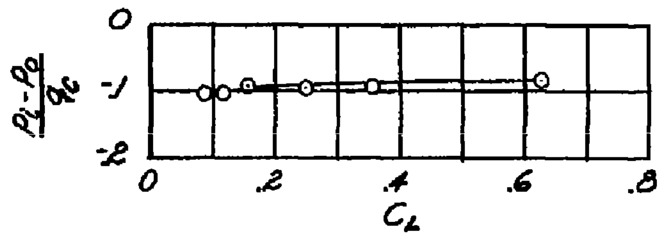


(a) Variation of $\frac{p_i - p_o}{q_c}$ with C_L from unaccelerated-flight data.

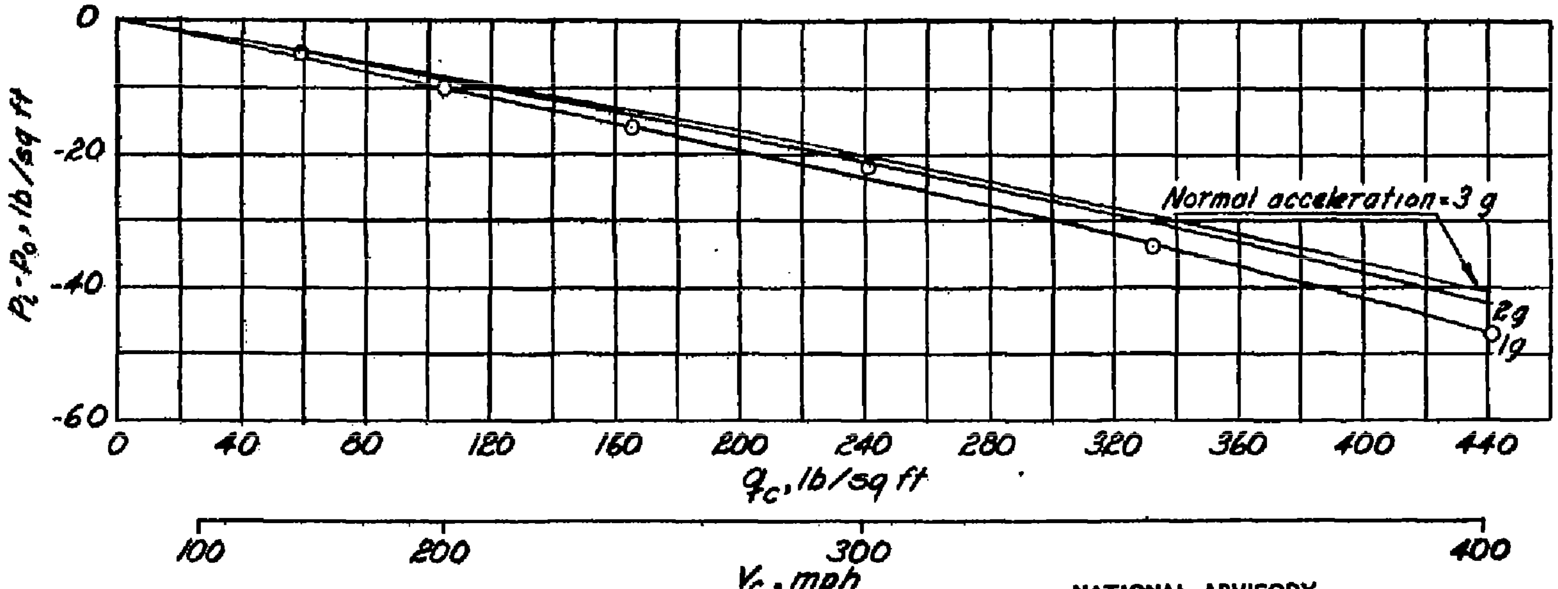


(b) Calculated effect of normal acceleration on cockpit pressure.

Figure 9.- Effect of normal acceleration on cockpit pressure for airplane A.



(a) Variation of $\frac{p_i - p_o}{q_o}$ with C_L from unaccelerated-flight data.



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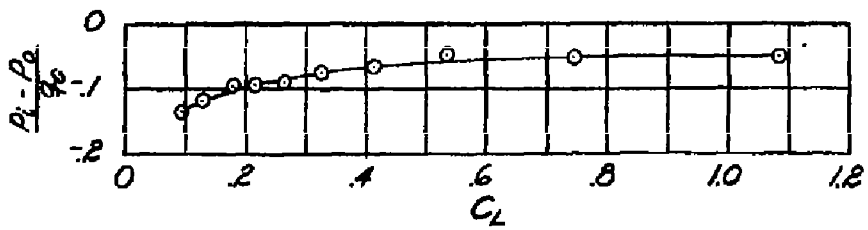
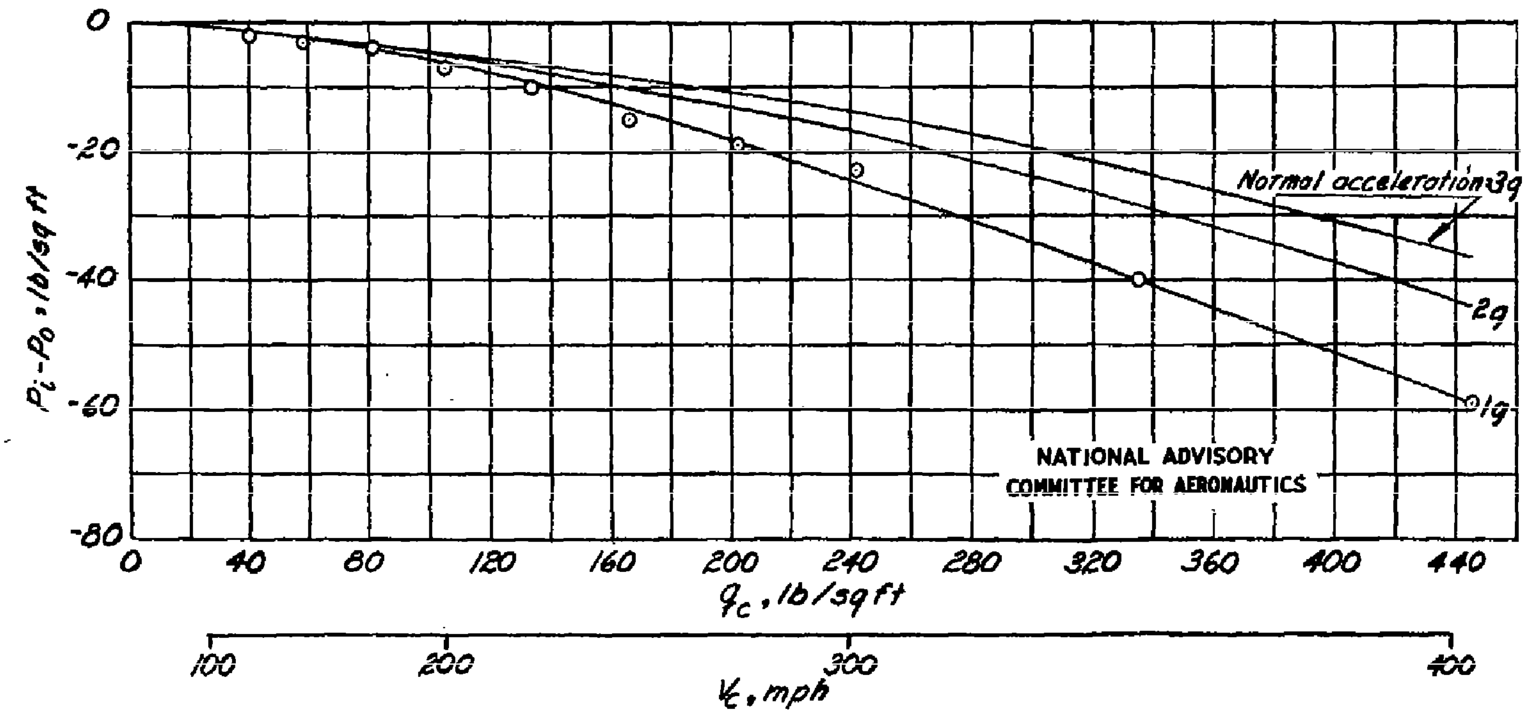
(b) Calculated effect of normal acceleration on cockpit pressure.
Figure 10.- Effect of normal acceleration on cockpit pressure for airplane D.



(a) Variation of $\frac{p_i - p_o}{q_c}$ with C_L from unaccelerated-flight data.



(b) Calculated effect of normal acceleration on cockpit pressure.

Figure 11.- Effect of normal acceleration on cockpit pressure for airplane E.

TITLE: Flight Measurements of Internal Cockpit Pressures in Several Fighter-Type Airplanes

AUTHOR(S): Danforth, E. C. B.; Reeder, John P.

ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C.

PUBLISHED BY: (Same)

ATI- 8193

REVISION (None)

ORIG. AGENCY NO. TN-1173

PUBLISHING AGENCY NO.

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Feb '47	Unclass.	U.S.	Eng.	29	photos, graphs

ABSTRACT:

Measurements were taken in airplanes equipped with either conventional or bubble canopies. Data show variation in cockpit pressure with indicated air speed and angle of sideslip for both open and closed canopy conditions. Change in cockpit pressure accompanying change in engine power was small. Data also show the variation of cockpit pressure with normal acceleration at constant value of free-stream impact pressure. A method is outlined for predicting cockpit pressure in accelerated flight from measurements made in unaccelerated flight.

DISTRIBUTION: Request copies of this report only from Originating Agency

DIVISION: Flight Testing (13)

SECTION: Miscellaneous Testing (9)

SUBJECT HEADINGS: Cockpit pressure, Flight induced (23519)

ATI SHEET NO.: R-13-9-1