NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

February 1945 as
Advance Confidential Report L5A30

A SUMMARY OF DRAG RESULTS FROM RECENT LANGLEY FULL-SCALE-TUNNEL TESTS OF ARMY AND NAVY AIRPLANES

By Roy H. Lange

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NACA ACR No. L5A30

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE CONFIDENTIAL REPORT

A SUMMARY OF DRAG RESULTS FROM RECENT LANGLEY FULL-SCALE-TUNNEL TESTS OF ARMY AND NAVY AIRPLANES

By Roy H. Lange

SUMMARY

The results of drag investigations of twelve military airplanes tested in the Langley full-scale tunnel for the purpose of increasing their speed are summarized in this report. The purpose of this report is to point out undesirable aerodynamic features as a guide to airplane designers.

The drag data include results of tests to determine the effects of the cowling and cooling arrangements, the wing-surface irregularities, the leakage, the landing-gear installations, the canopies, the radio antennas, and the armament installations on the drag of the airplane. In order to simplify the presentation of the data, perspective drawings are used to show the original installations and the modifications investigated. Included on each drawing is a discussion of the main results of the tests.

The results of the tests indicate that the elimination of leakage and attention to detail design offer possibilities for considerably reducing the drag.

INTRODUCTION

Drag investigations have been made in the Langley full-scale tunnel of a large number of military airplanes for the purpose of increasing their speed. In most cases, large reductions in drag were found to be obtained by careful detail design and by relatively simple modifications to existing designs. A summary of the results of the investigations prior to 1940 was reported in reference 1. The data presented in the present report are an extension of the data presented in reference 1 and include the results of tests since 1940. A special effort has been made to present these findings in a detailed manner, with the aid of sketches, in order that the sources of excessive drag could be clearly illustrated and methods discussed for their elimination. Because of the wide variety of test conditions, the drag values are not directly comparable from one airplane to another and these data should be considered as qualitative indications of good or undesirable design practice. This report is not intended to be used as a design manual but rather to illustrate undesirable design features.

The standard procedure with each of the twelve airplanes investigated was to evaluate the drag of as many of the component items and installations as was feasible. This evaluation was accomplished by determining the drag of the airplane in successive conditions from a faired and sealed smooth airplane to the service condition. If excessive drags were discovered, attempts were made to determine the improvements possible within practical limits. Many of these modifications indicated good design methods for treating similar items.

The data include the effects on the drag of an airplane of several internal-flow systems for power-plant installations, such as annular cowling inlets, wing-duct inlets, underslung fuselage ducts, oil and coolant ducts, carburetor intakes, and exhaust stacks. The effect on drag of leakage through wing-fold axes, cowling-flap hinge-line gaps, landing gears, tail-surface gaps, armament gaps, and cooling-air ducts is shown. Data are also presented showing the drag increments due to the wing-surface irregularities, the arrangement of armament, the shape of canopy, and the radio-antenna installation. The individual drag of many of these items is small. The sum of their drag effects, however, will considerably decrease the airplane speed. The velocity decrements given on the figures were calculated for the airplanes tested at their maximum level-flight speeds and will become larger as airplanes become faster. Certain types of items, such as cylindrical protrusions and refaired bulges, may have a greater drag at full-flight speed than wind-tunnel measurements indicate because of compressibility effects which occur at the higher speeds.

SYMBOLS

ΔC_D increment of drag coefficient

ΔV increment of airplane velocity, miles per hour

C_D drag coefficient $\left(\frac{\text{Drag}}{q_o S}\right)$

C_L lift coefficient $\left(\frac{\text{Lift}}{q_o S}\right)$

ρ mass density of air, slugs per cubic foot

q_o free-stream dynamic pressure $\left(\frac{1}{2}\rho V_o^2\right)$, pounds per square foot

Q quantity rate of flow, cubic feet per second unless otherwise specified

$\frac{Q}{V_o}$ air-flow parameter, square feet

$\frac{V_i}{V_o}$ inlet-velocity ratio

V_i inlet velocity, feet per second

V_o free-stream velocity, feet per second

S wing area, square feet

α_T angle of attack of thrust axis, degrees

H total pressure, pounds per square foot

p_o free-stream static pressure, pounds per square foot

AIRPLANES AND EQUIPMENT

Photographs of the airplanes mounted on the balance-support struts in the Langley full-scale tunnel are presented in figure 1. The basic dimensions and general airplane characteristics for each airplane are presented in the three-view drawings (fig. 2). For convenience, the airplanes are identified by numbers.

The Langley full-scale tunnel and balance system are described in reference 2.

METHODS AND TESTS

The usual procedure in the tests was first to fair or remove all protrusions on the airplane and seal all points where air leakage was suspected. With the airplane in this condition, which is referred to herein as the sealed and faired condition, a force test was made at a tunnel airspeed of 100 miles per hour to determine the drag of the airplane in the high-speed attitude. The seals and fairings were then progressively removed and the drag increment due to each change was determined. In some cases the order in which seals and fairings were removed determined the amount of drag measured, and an attempt was made in all the tests to isolate as many drag items as possible. The results of such a series of tests, which were made to evaluate the drag of airplane 6, are given in table I. Except as noted in the presentation of results, all of the tests were made with the propellers removed from the airplanes.

In most cases the motion of wool tufts attached to the airplane surface was observed as an aid to the discovery of poor air-flow conditions. Static-pressure measurements, in addition, were made at several points on the airplanes by means of flush-type orifices in order to determine the speeds at which compressibility effects might become important.

Cowlings and ducts were tested with the inlets and outlets completely sealed and with the inlets and outlets open (high-speed condition) in order that the drag due to the cooling-air flow could be determined. In conjunction with these tests, air-flow quantities through the ducts were determined from measurements of the total and the static pressures at the cooling-air outlets.

RESULTS AND DISCUSSION

The drag coefficients of the airplanes in the sealed and faired condition and in the service condition are presented in table II. In addition, a summary of the important drag increments that were determined for each airplane in its high-speed attitude is given in table II.

The principal results of the drag investigations are presented in figures 3 to 40. These figures show perspective drawings of the original installations and the modifications investigated, together with the drag increments measured during each test and the corresponding decrements in the maximum speed. In order to facilitate the use of these data as a reference for airplane designers, a brief description of the test results is given on each figure. The results are discussed herein under the following headings: power-plant installations, installations in the wings, empennages, armament installations, canopies, and radio antennas.

Power-Plant Installation

The power-plant installation, which includes the engine and its accessories, such as the cooling units, the supercharger, and the exhaust stacks, frequently increases the drag of an airplane more than any other item and especially careful attention must therefore be given to its design. The data on cooling systems are presented from consideration of the drag of the cooling systems in the high-speed condition and, if available, data for other flight conditions are commented upon.

Investigations to decrease the drag of the air-cooled-engine installations on airplanes 1, 2, and 3 are described in figures 3 to 6. During these investigations, substantial increases in drag were found to result from leakage through gaps at the cowling-flap hinge lines. The effect of these gaps on the drag of airplanes 6, 8, and 10 is discussed in figure 7. If effective sealing of gaps is not possible, the drag can be reduced by designing the gaps to direct the air leakage backward parallel to the direction of the external air flow.

Results of full-scale-tunnel measurements of the drag and cooling-air-flow characteristics of ducts located at various places on airplanes 3, 4, 7, and 11 are described in figures 8 to 16. More complete results of tests, which include recommended design procedure, of ducts located at the wing leading edge, the rear portion of the bottom of the fuselage, and the forward portion of the top of the fuselage of airplane 7 are described in references 4 to 6. The data in references 4 to 6 include measurements of velocity distribution, total pressure, and drag made at air-flow quantities and angles of attack corresponding to a wide range of flight conditions. Discussions of the design criterions for duct systems of power-plant installations are given in reference 7.

The drag caused by the exhaust-stack installations on five airplanes is described in figures 17 to 20. The sources of unnecessary drag of exhaust-stack installations are large-bore protruding stacks (figs. 17 and 18) and unnecessary air leakage that is not directed backward parallel to the external flow (fig. 19). If a collector system must be used, the drag can be kept low by placing the stacks close to the fuselage to keep the form drag low, pointing the stack openings rearward to regain the thrust of the exhaust gases, and sealing around the stacks to give the minimum air flow for shroud cooling. Studies have been made to determine means for recovering part of the energy of exhaust gases in the form of jet thrust and the results indicate that considerable gains may be obtained with individual jet exhaust stacks. The criterions for the design of these stacks are presented in reference 8.

The effect on drag of installing an external turbosupercharger unit on airplane 5 is described in figure 21. It is important that supercharger units be submerged or enclosed in a smooth fairing on high-speed airplanes.

Installations in Wings

Because of the armament requirements of present-day airplanes, numerous installations in the wings have been necessary, such as gun-access and ammunition doors, shell-ejection slots, and inspection plates. Carrier-based airplanes, in addition, must be equipped with folding wings to facilitate storage in the hold. These items, unless carefully designed, will generally increase the wing drag considerably by causing air leakage through the wings and wing-surface irregularities. On retractable-landing-gear installations, the main sources of drag arise from leakage and turbulent flow around open and partly open wheel wells. Internal sealing can reduce the drag by eliminating air leakage at the upper wing surfaces and at the lower wing surfaces around open and partly open wheel wells. On airplanes 6 and 10 there was a combination of leakage effects. Air entered the wings through openings at the wheel well (figs. 27 and 29) and leaked out through joints in the upper wing surfaces (figs. 23 and 24) causing a drag increase. Internal sealing of the wheel well should considerably reduce the drag of the combination. Gun ports at the wing leading edge are other points of air leakage and should be internally sealed. The effects on drag of wing-surface irregularities and air leakage on airplanes 6, 8, 9, 10, and 12 are described in figures 22 to 29.

Empennages

Large gaps between the fixed and the movable tail surfaces have been found to cause increases in drag and to lower the effectiveness of the tail surfaces. Three typical examples of the drag increments caused by tail-surface gaps are shown in figure 30.

Failure to enclose the tail wheel and arresting hook in a suitable sealed fairing increased the drag coefficient of airplane 10 as described in figure 31.

Armament

Careful fairing of protrusions and complete sealing around external-armament installations ensure low drag. Examples of several armament installations for which fairing and sealing modifications provided drag reductions are given in figures 32 to 35. The effect on drag of stowing the rear gun of airplane 8 is described in figure 36.

Canopies

Short afterbodies and sharp edges should be avoided on airplane canopies since they cause flow separation and low critical speeds. Points of air leakage through canopies should be eliminated, if possible. The results of tests to improve the canopy installations on airplanes 4 and 9 are described in figures 37 and 38.

Radio Antenna

Three examples of radio-antenna installations considered to have excessive drag are shown in figure 39. Radio-antenna installations for which no appreciable drag was measured are shown in figure 40. The use of masts with thickness ratios of the order of 25 percent has been found to be the main source of drag on radio-antenna installations. If a mast must be used, the type of mast used on airplane 12, which was a thin flat metal rod, is recommended.

CONCLUDING REMARKS

The results of drag investigations on twelve present-day military airplanes demonstrate that worthwhile drag reductions can be obtained by relatively simple sealing and fairing modifications. Elimination of leakage and attention to detail design appear to offer the best possibilities for drag reductions on airplanes that are relatively clean aerodynamically.

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

REFERENCES

1. Dearborn, C. H., and Silverstein, Abe: Drag Analysis of Single-Engine Military Airplane Tested in the NACA Full-Scale Wind Tunnel. NACA ACR, Oct. 1940.

2. DeFrance, Smith J.: The N.A.C.A. Full-Scale Wind Tunnel. NACA Rep. No. 459, 1933.

3. Silverstein, Abe, and Guryansky, Eugene R.: Development of Cowling for Long-Nose Air-Cooled Engine in the NACA Full-Scale Wind Tunnel. NACA ARR, Oct. 1941.

4. Nelson, W. J., and Czarnecki, K. R.: Wind-Tunnel Investigation of Wing Ducts on a Single-Engine Pursuit Airplane. NACA ARR No. 3J13, 1943.

5. Czarnecki, K. R., and Nelson, W. J.: Wind-Tunnel Investigation of Rear Underslung Fuselage Ducts. NACA ARR No. 3I21, 1943.

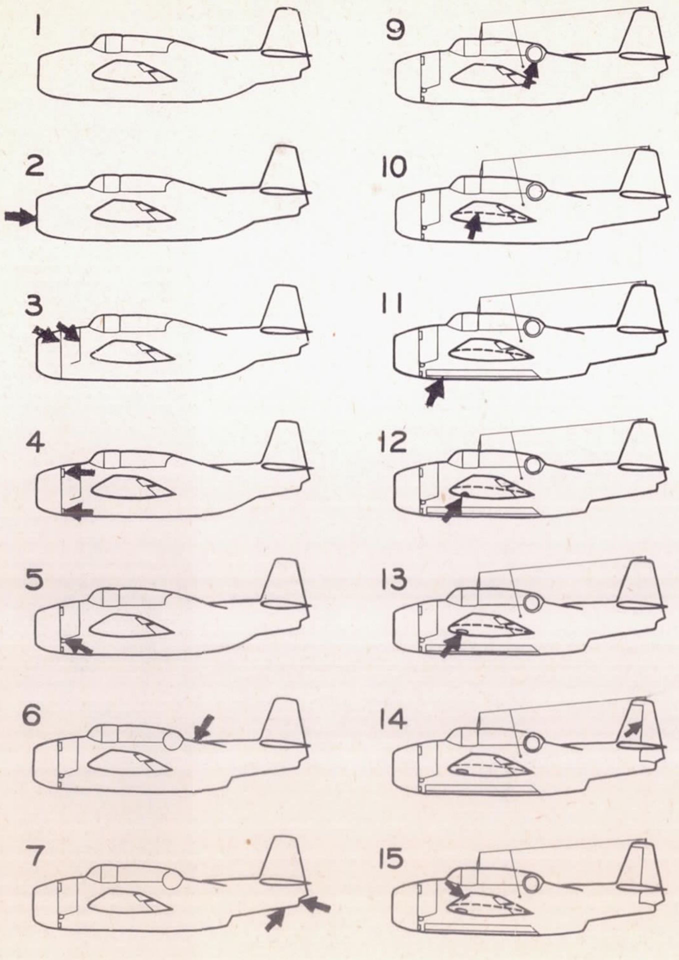
6. Nelson, W. J., and Czarnecki, K. R.: Wind-Tunnel Investigation of Carburetor-Air Inlets. NACA ARR, Feb. 1942.

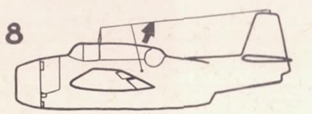
7. Henry, John R.: Design of Power-Plant Installations. Pressure-Loss Characteristics of Duct Components. NACA ARR No. L4F26, 1944.

8. Pinkel, Benjamin, Turner, L. Richard, and Voss, Fred: Design of Nozzles for the Individual Cylinder Exhaust Jet Propulsion System. NACA ACR, April 1941.

TABLE I.- TYPICAL DRAG INVESTIGATION IN LANGLEY FULL-SCALE TUNNEL

[AIRPLANE 6]





Condition	Airplane configuration	C_D at $C_L = 0.245$	Reference condition (See column 1)	ΔC_D
1	Airplane completely sealed and faired	0.0183	-----	-----
2	Flat plate removed from nose	.0189	1	0.0006
3	Seals removed from flapped-cowling air exits	.0199	2	.0010
4	Seals removed from cowling-flap hinge-line gaps	.0203	3	.0004
5	Exhaust stacks replaced	.0211	4	.0008
6	Canopy fairing removed, turret leaks sealed	.0222	5	.0011
7	Tail wheel and arresting-hook openings uncovered	.0223	6	.0001
8	Aerial, mast, and trailing antenna tube installed	.0227	7	.0004
9	Canopy and turret leak seals removed	.0230	8	.0003
10	Leak seals removed from shock strut, cover plate, and wing-fold axis	.0234	9	.0004
11	Leak seals removed from bomb-bay doors and miscellaneous leak seals removed	.0236	10	.0002
12	Fairings over catapult hooks removed	.0237	11	.0001
13	Wheel-well cover plates removed	.0251	12	.0014
14	Seals removed from tail-surface gaps	.0260	13	.0009
15	Plates over wing-tip slot openings removed. Airplane in service condition	.0264	14	.0004
	Total-drag change			.0081

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

[redacted]

TABLE II.- INDEX OF IMPORTANT DRAG RESULTS

[Numbers in parentheses refer to figures]

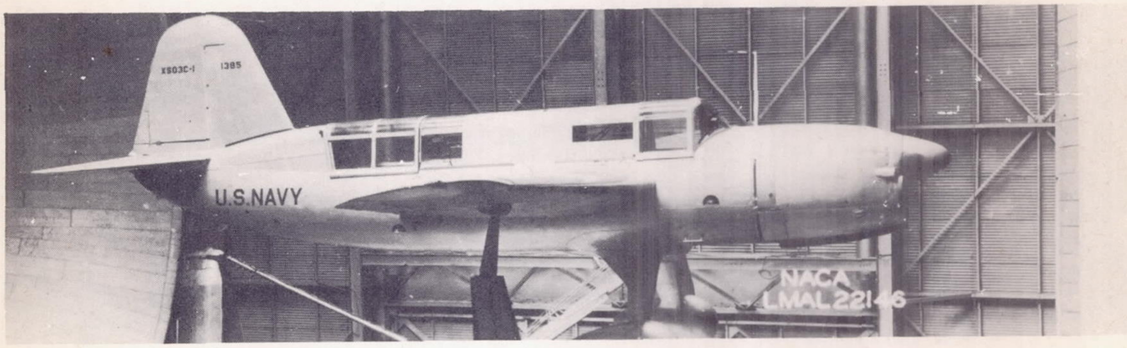
Item \ Airplane	1	2	3	4	5	6	7	8	9	10	11	12
						C_D						
Airplane sealed and faired	0.0205	0.0313	0.0282	0.0222		0.0183	0.0160	0.0219	0.0215	0.0210	0.0171	0.0173
Airplane in service condition	.0243	.0337	.0386	.0293	[a]0.0361	.0264		.0280	.0284	.0293	.0221	.0208
						ΔC_D						
Engine cowling	0.0040 (3(a))	[b]-0.0004 (5)	0.0041 (6)									
Cowling-flap and hinge-line-gap leakage						0.0004 (7(a))		0.0005 (7(b))		0.0005 (7(c))		
Wing-duct inlets											0.0017 (10)	
Coolant-radiator installation				0.0021 (12(a))								
Oil-cooler installation			.0018 (14(a))	.0008 (12(b))								
Vanes installed in rear underslung fuselage duct							[b]-0.0004 (13)					
Carburetor scoops							.0002 (15(a))					
Exhaust stacks						.0008 (18)		.0021 (17)	0.0010 (19)		.0005 (20(a))	0.0007 (20(b))
Supercharger installation					0.0040 (21(a))							
Wing-fold-axis leakage and gun-access doors						.0004 (24)			.0012 (22)	.0007 (23)		.0005 (25)
Sanded walkways									.0010 (26)			
Landing gear						.0014 (27(c))		.0005 (28)		.0009 (29(a))		
Armament				.0008 (32)				.0007 (36)	.0002 (35(a))	.0004 (35(b))	.0017 (33(a), 34)	.0005 (35(c))
Tail-surface-gap leakage						.0009 (30(a))				.0005 (30(b))	.0007 (30(c))	
Tail wheel and arresting hook										.0005 (31)		
Canopy modification									-.0004 (37)			
Radio antenna		.0004 (39(c))				.0004 (39(a))				.0003 (39(b))	0 (40(a))	0 (40(b))

[a]Estimated drag coefficient.
[b]Modifications.

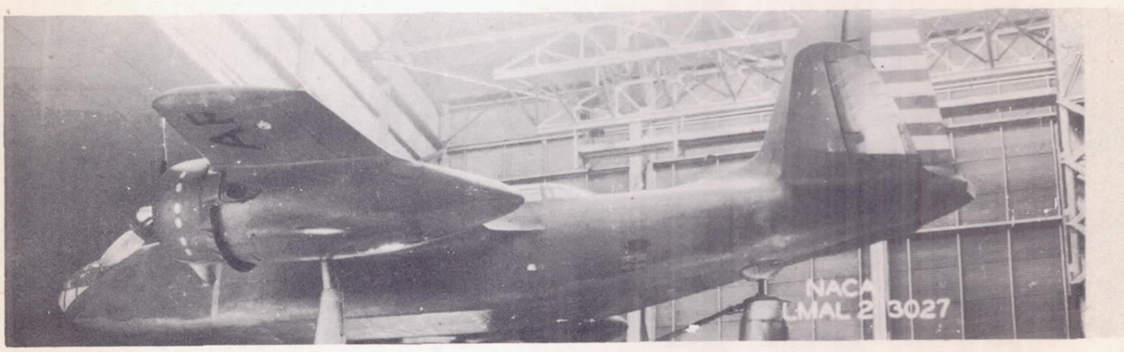
[redacted]

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

(a) Airplane 1. Service condition; propeller removed.



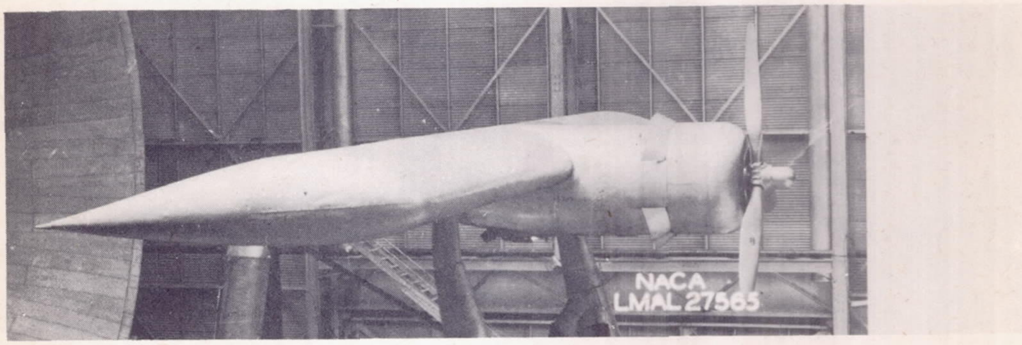
(b) Airplane 2. Service condition; propeller removed.



(c) Airplane 3. Service condition except for sealed cowling holes; outer-wing panels removed.

Figure 1.- Airplanes mounted for tests in Langley full-scale tunnel.

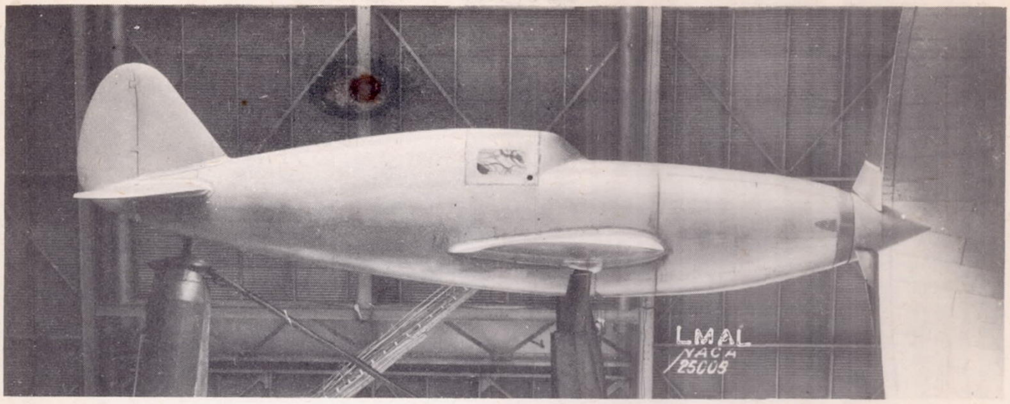
(d) Airplane 4. Service condition; propellers removed.



(e) Airplane 5. Engine-nacelle installation; propeller installed.

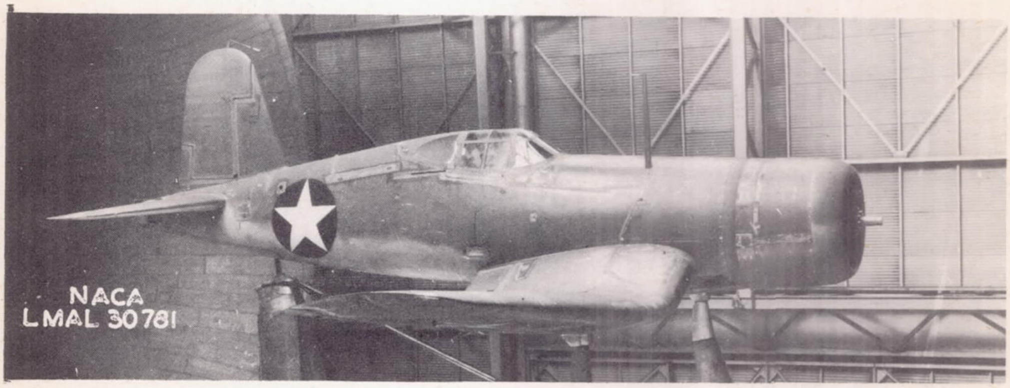
(f) Airplane 6. Service condition; propeller removed.

Figure 1.- Continued. [redacted]



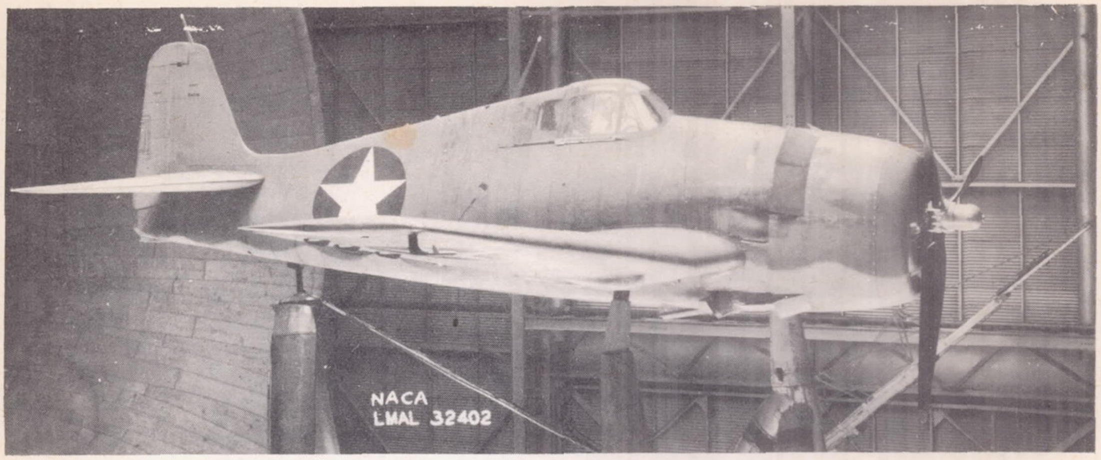
(g) Airplane 7. Tunnel mock-up; propeller installed.

(h) Airplane 8. Sealed and faired condition; propeller removed.

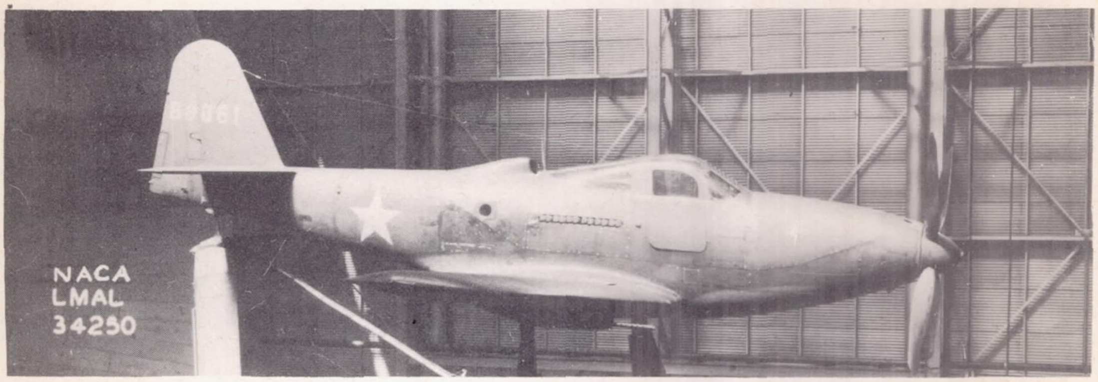


(i) Airplane 9. Service condition; propeller removed.

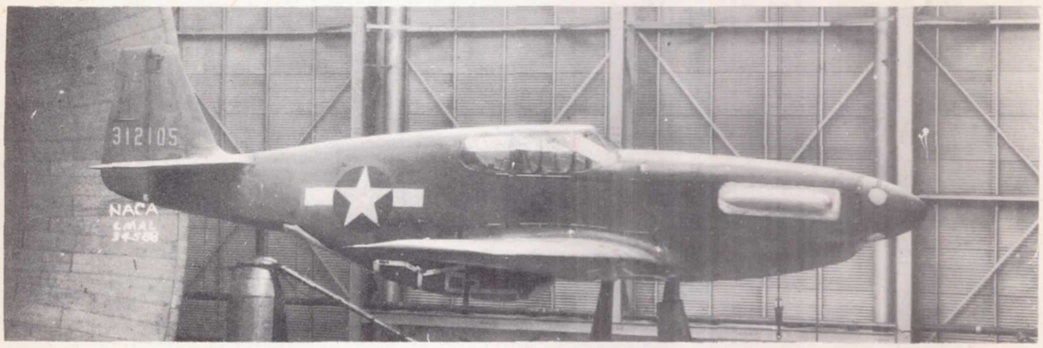
Figure 1.- Continued. [redacted]



(j) Airplane 10. Service condition.



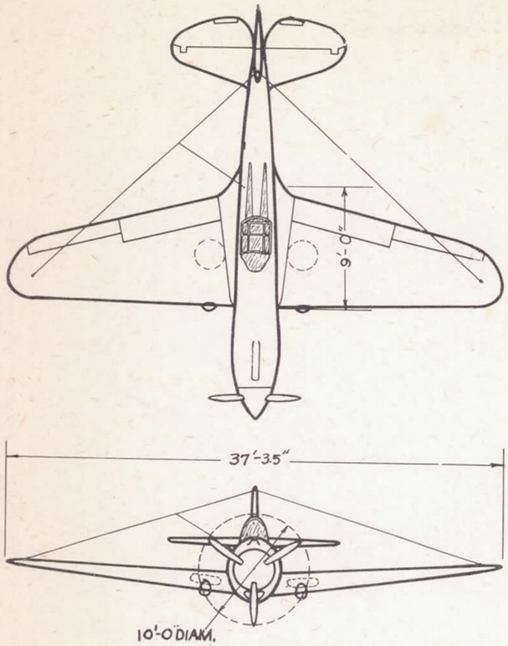
(k) Airplane 11. Service condition.



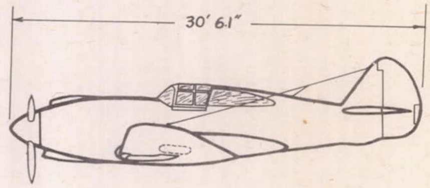
(l) Airplane 12. Sealed and faired condition; propeller removed.

CONFIDENTIAL

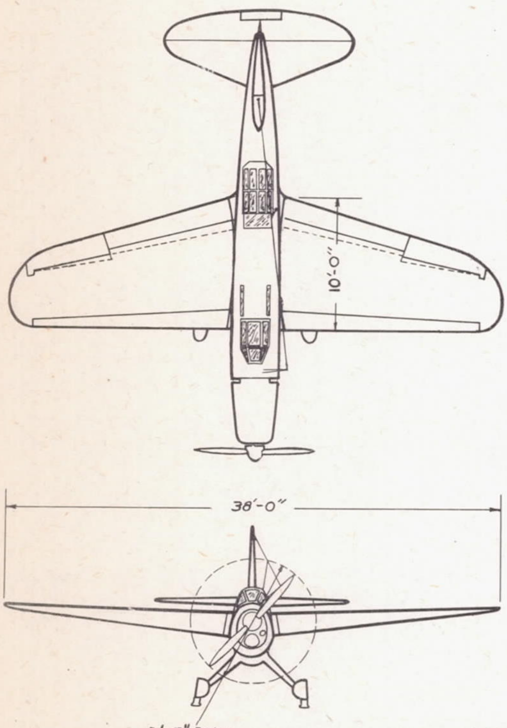
Figure 1.- Concluded.



Weight ------------------ 6000 lb
Wing section
  Root ---------------- NACA 2215
  Tip ----------------- NACA 2209
Wing area ------------ 236.0 sq ft
Twin-row engine
Military 1000 hp at 2700 rpm at 14,500 ft
Propeller gear ratio ---------- 16:9

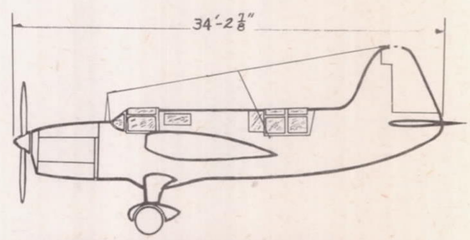


AIRPLANE 1



Weight ---------------- 5556 lb
Wing section
  Root ------------ NACA 23017
  Tip ------------- NACA 23009
Wing area ------------ 290.0 sq ft
Inverted-vee 12-cylinder engine
450 hp at 3000 rpm at 12,000 ft
Propeller gear ratio ---------- 3:2

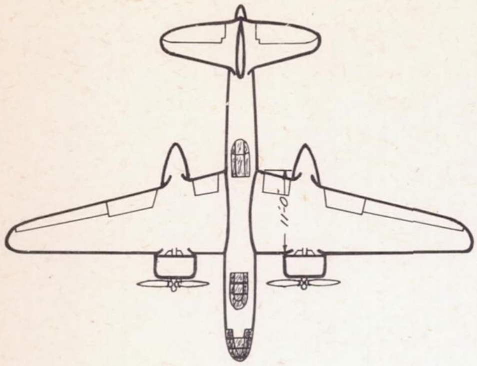
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



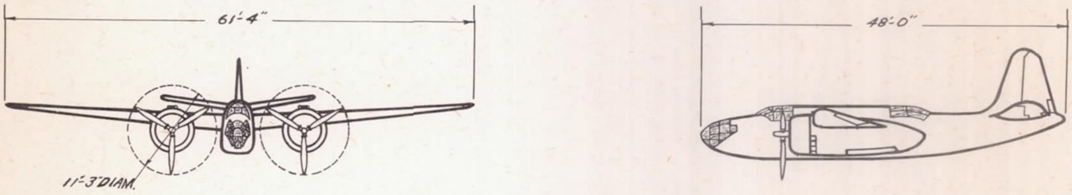
AIRPLANE 2

CONFIDENTIAL

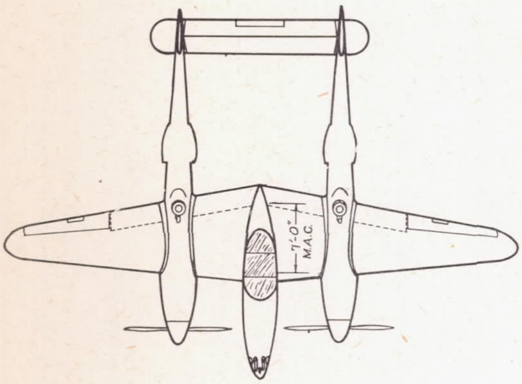
Figure 2.- Basic dimensions and general airplane characteristics of twelve airplanes tested.



Weight ________________ 19,150 lb
Wing section
  Root ____________ NACA 23018
  Tip ____________ NACA 23009
Wing area ____________ 465.0 sq ft
Two twin-row engines
1400 hp at 2400 rpm at 11,500 ft
Propeller gear ratio _________ 16:9

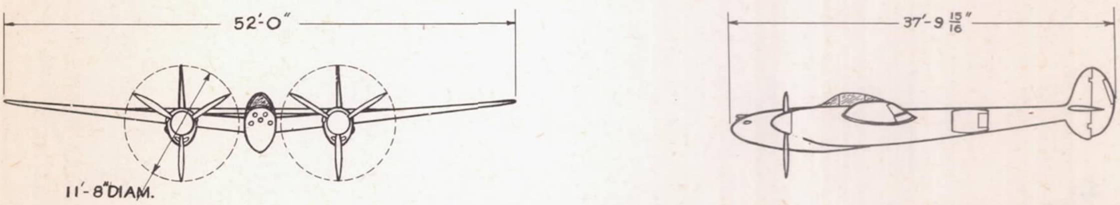


AIRPLANE 3



Weight ________________ 14,500 lb
Wing section
  Root ______________ NACA 23016
  Tip ______________ NACA 23009
Wing area ________________ 327.5 sq ft
Two inline liquid-cooled supercharged engines
1400 hp at 3000 rpm at 25,000 ft
Propeller gear ratio ____________ 2:1

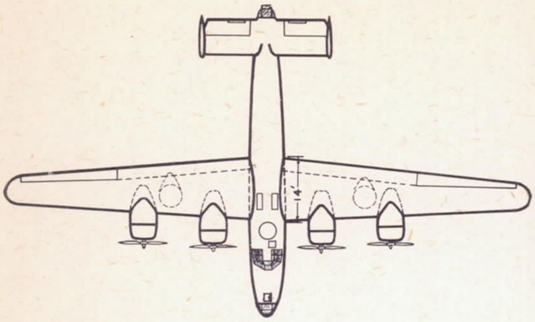
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



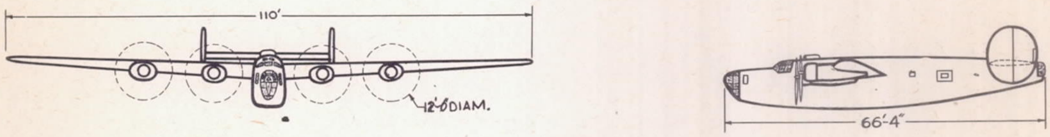
AIRPLANE 4

CONFIDENTIAL

Figure 2.- Continued.

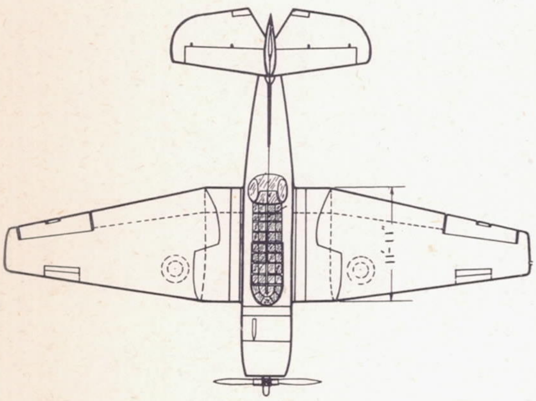


Weight ________________ 56,000 lb
Wing section
  Root ________________ C.A.C. 22%
  Tip ________________ C.A.C. 9.3%
Wing area ______________ 1048.0 sq ft
Four twin-row two-speed-supercharged engines
1200 hp at 2600 rpm at 25,000 ft
Propeller gear ratio ____________ 16:9

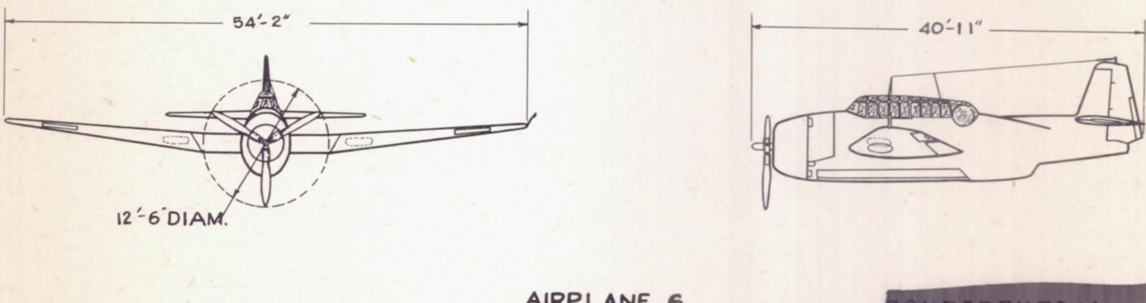


AIRPLANE 5

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



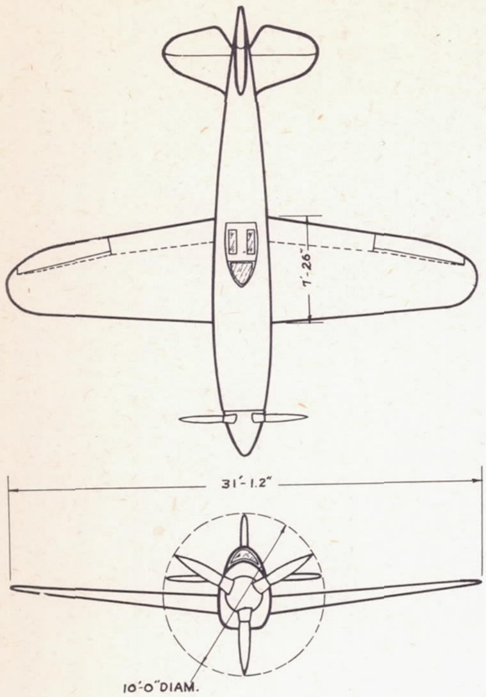
Weight ____________________ 14,452 lb
Wing section
  Root __________________ NACA 23015
  Tip __________________ NACA 23009
Wing area ________________ 490.0 sq ft
Twin-row two-speed-supercharged engine
1350 hp at 2400 rpm at 13,000 ft
Propeller gear ratio _____________ 16:9



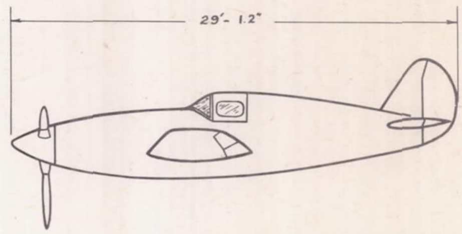
AIRPLANE 6

CONFIDENTIAL

Figure 2.- Continued.

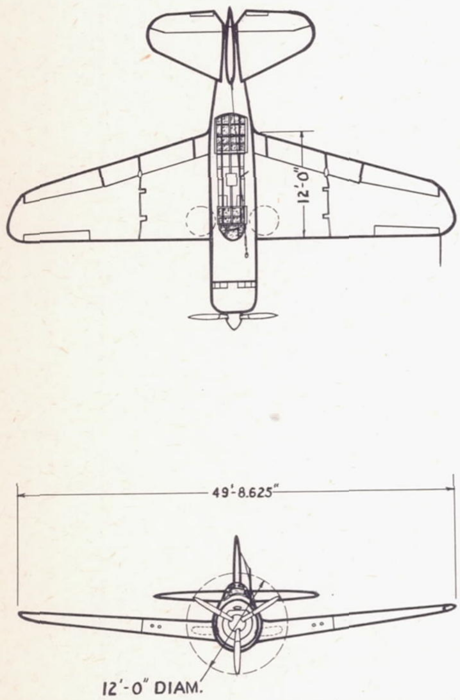


Weight ______________ 6500 lb
Wing section
  Root ____________ NACA 23016.5
  Tip ____________ NACA 23009
Wing area ____________ 170.0 sq ft
Inline liquid-cooled engine
1150 hp at 3000 rpm at 12,000 ft
Propeller gear ratio __________ 2:1

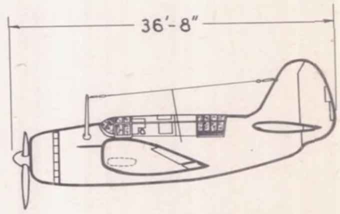


AIRPLANE 7

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



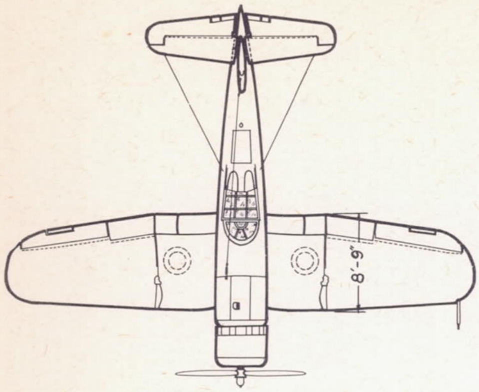
Weight ________________ 12,777 lb
Wing section
  Root ______________ NACA 23017
  Tip ______________ NACA 23009
Wing area ______________ 442.0 sq ft
Twin-row two-speed-supercharged engine
1350 hp at 2400 rpm at 13,000 ft
Propeller gear ratio ____________ 16:9



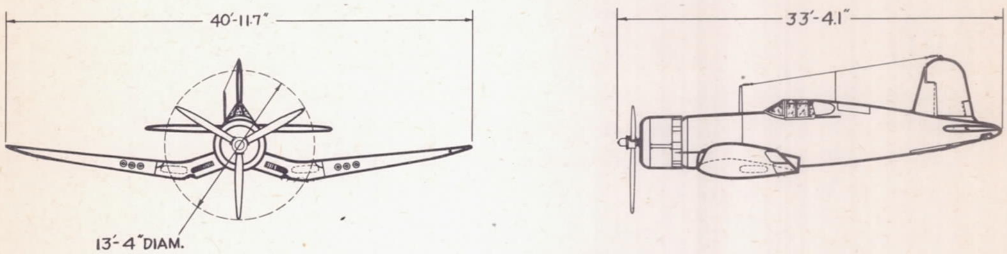
AIRPLANE 8

[redacted]

Figure 2.- Continued.

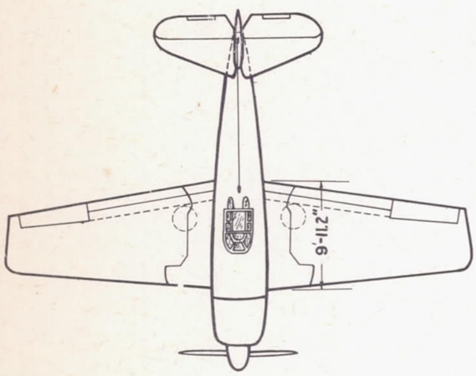


Weight .... 11,001 lb
Wing section
Root .... NACA 23015
Tip .... NACA 23009
Wing area .... 314.0 sq ft
Twin-row two-stage-supercharged engine
1550 hp at 2550 rpm at 25,500 ft
Propeller gear ratio 2:1

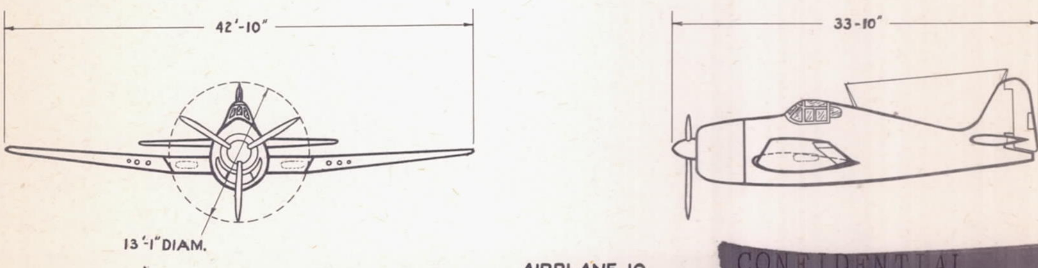


AIRPLANE 9

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



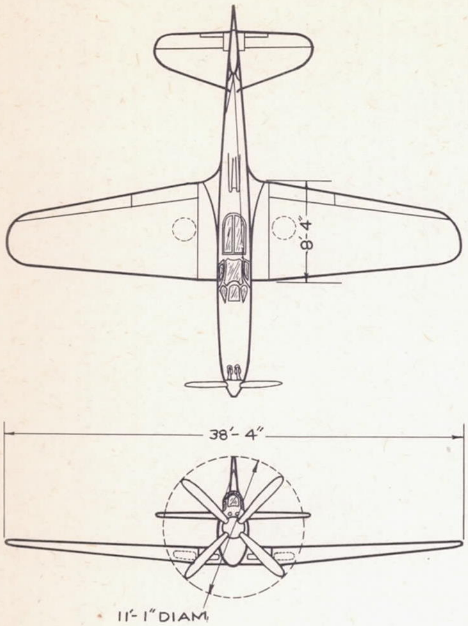
Weight .... 11,441 lb
Wing section
Root .... NACA 23015.6 (Modified)
Tip .... NACA 23009
Wing area .... 334.0 sq ft
Twin-row two-stage-supercharged engine
1650 hp at 2700 rpm at 25,000 ft
Propeller gear ratio 2:1



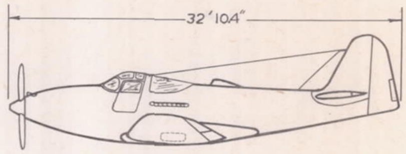
AIRPLANE 10

CONFIDENTIAL

Figure 2.- Continued.

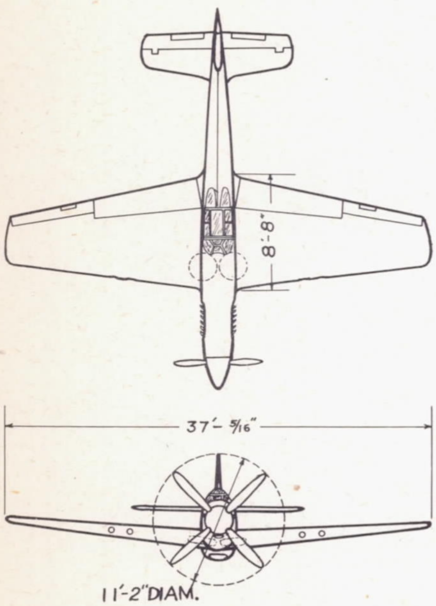


Weight ____________________ 7662 lb
Wing section
Root _______________ NACA 66 series
Tip _______________ NACA 66 series
Wing area _______________ 248.0 sq ft
Inline liquid-cooled auxiliary-stage-supercharged engine
1150 hp at 3000 rpm at 22,400 ft
Propeller gear ratio _____________ 2.23:1

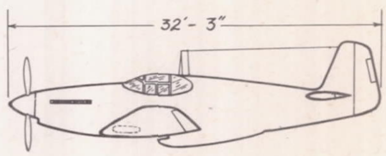


AIRPLANE 11

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

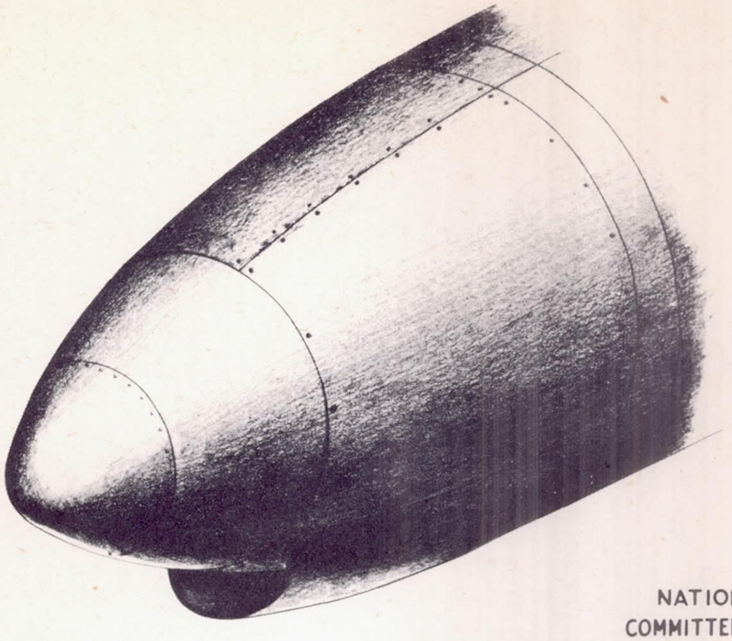


Weight ____________________ 8412 lb
Wing section __ NACA-NAA compromise low drag
Wing area _______________ 233.2 sq ft
Inline liquid-cooled supercharged engine
1300 hp at 3000 rpm at 24,200 ft
Propeller gear ratio ____________ 44:21

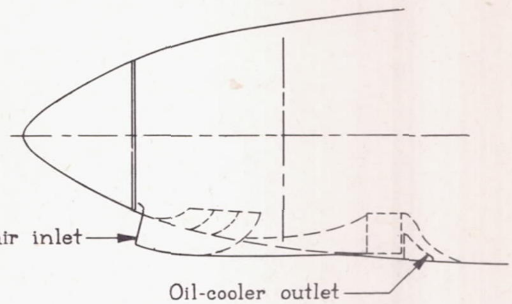


AIRPLANE 12

Figure 2.- Concluded.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



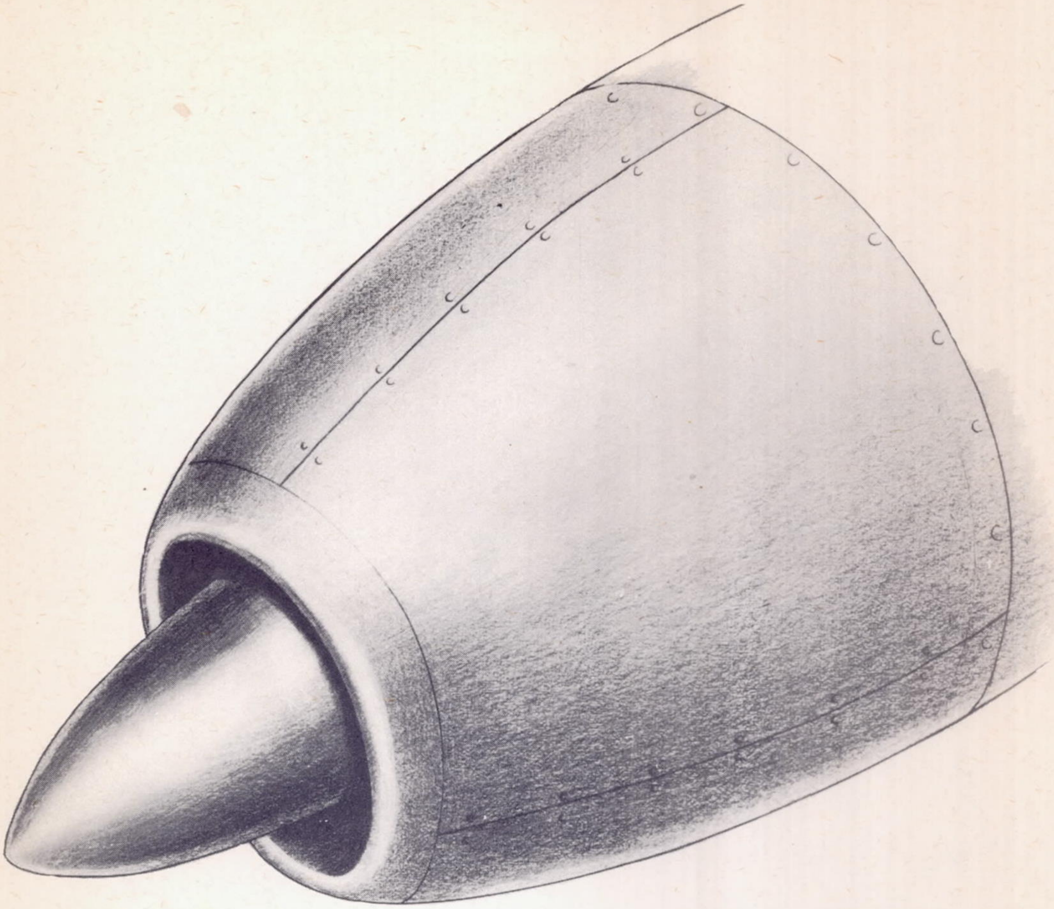
ΔC_D, 0.0040 Q, 16,000 cu ft per min

ΔV, 17 mph $H - p_o$, $0.40q_o$

(a) Original long-nose cowling.

Figure 3.- Cowling drag on airplane 1.

The original long-nose cowling on airplane 1, which had a 20-inch propeller-shaft extension to permit a cowling shape of higher fineness ratio, included an inlet that was too small and leading edges that were too sharp. The sudden change in direction and the extreme expansion of the high-velocity cooling air into the large volume ahead of the engine resulted in a total-pressure recovery in front of the engine cylinders of only $0.40q_o$. The drag coefficient was 0.0040 greater for the original installation with an exit area of 167 square inches (cooling flaps in closed position) and an air-flow quantity of approximately 16,000 cubic feet per minute at 350 miles per hour than for the sealed and smooth cowling with the scoop removed. Cowlings were developed in the Langley full-scale tunnel (figs. 3(b) and 3(d)) to reduce the drag of the original cowling.



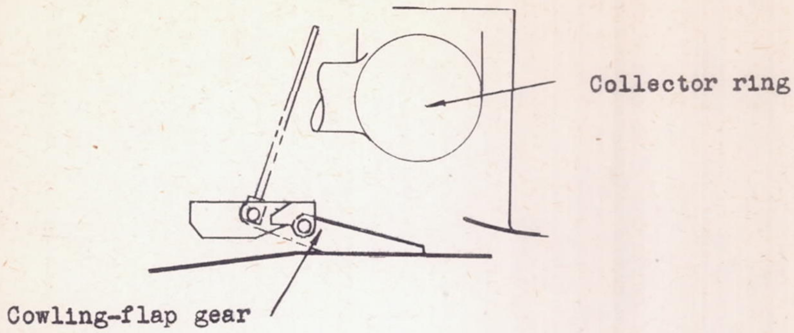
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0027 Q, 17,000 cu ft per min
ΔV, 13 mph $H - p_o$, $0.90q_o$

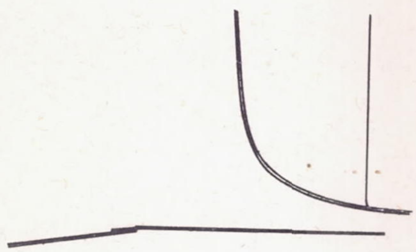
(b) Large annular inlet. Spinner A.

Figure 3.- Continued.

A cowling with an annular inlet and an inlet-velocity ratio of 0.25, designed to reduce the kinetic-energy losses of the cooling air and to avoid the large external drag of the original cowling (fig. 3(a)), was next tested. As compared with the sealed and smooth cowling with the scoop removed, the airplane drag coefficient was increased to 0.0022 with an air flow of approximately 12,000 cubic feet per minute and to 0.0027 with an air flow of approximately 17,000 cubic feet per minute. Pressure measurements along the spinner indicated a flow reversal caused by a high adverse pressure gradient. The total pressure at the rear of the diffuser was slightly less than $0.90q_o$ for these conditions. The dimensions of the annular-inlet cowling with spinner A are given in figure 4.



Section at original cowling outlet



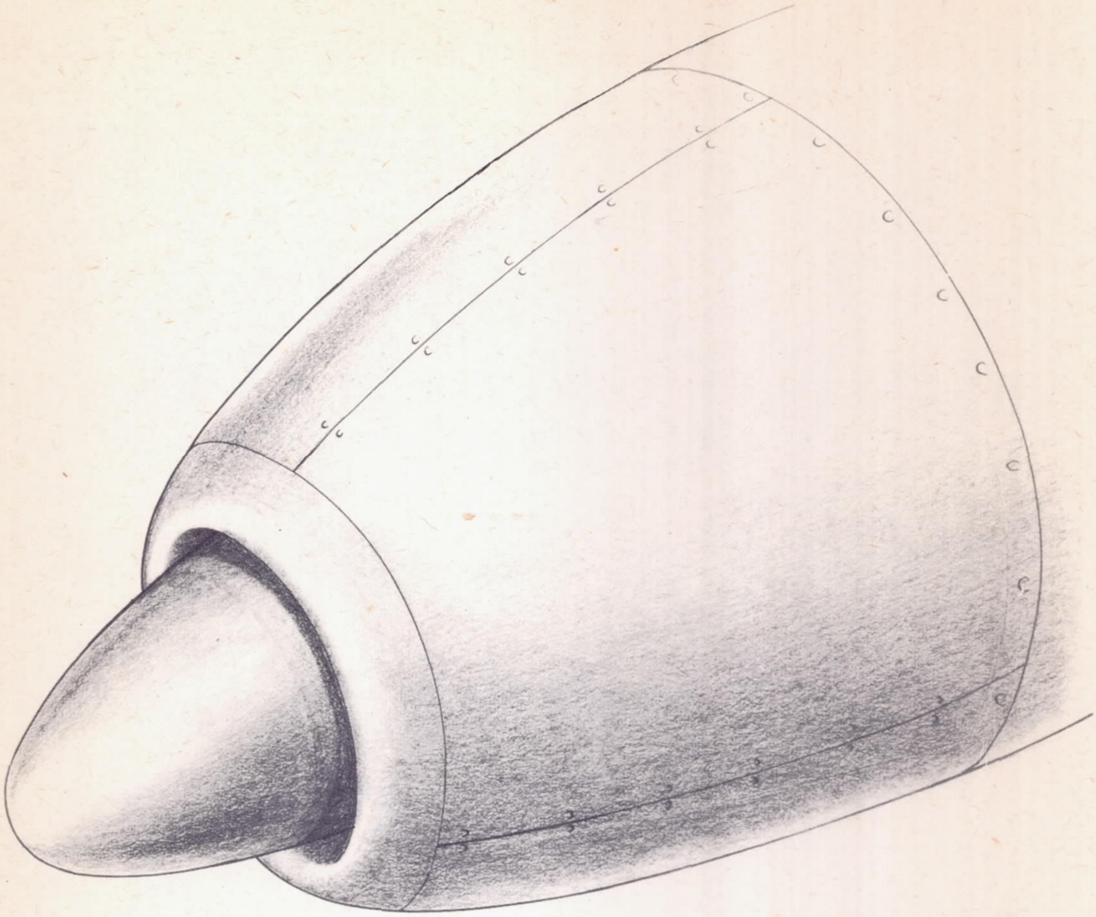
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Section at smooth cowling outlet

(c) Radial-engine-cowling outlet.

Figure 3.- Continued.

The drag of the annular-inlet cowling with spinner A was considered excessive and the outlet was next investigated (reference 3). Removing the cowling-flap gear and exhaust collector ring and installing a smooth outlet decreased the drag of the cowling by 0.0007 with an air flow of approximately 13,000 cubic feet per minute. In addition, a bottom exit was provided by removing the oil cooler and enlarging the oil-cooler exit to allow an engine-cooling-air flow of approximately 13,000 cubic feet per minute with the cowling flaps sealed. This arrangement further reduced the drag by 0.0004.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0012   Q, 21,000 cu ft per min
ΔV, 6 mph $H - p_o$, $0.97q_o$

(d) Small annular inlet. Spinner B.

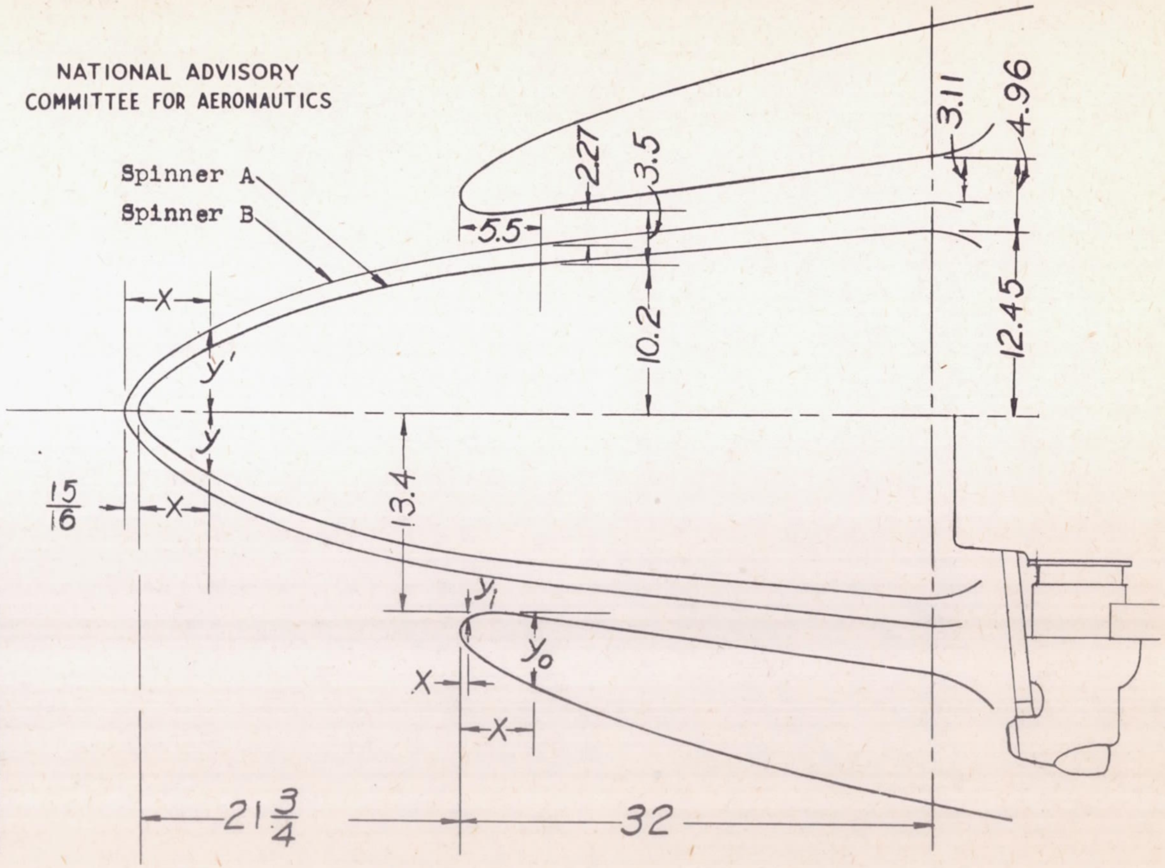
Figure 3.- Concluded.

In order to reduce the adverse pressure gradient along spinner A of figure 3(b) and to increase the total-pressure recovery in the diffuser, the inlet-velocity ratio was increased to about 0.5 on spinner B by increasing the spinner size and thus reducing the annular-inlet area. With the bottom exit open and the cowling flaps sealed, the cowling drag coefficient was reduced 0.0005 as compared with that measured with spinner A and the same outlet, and the air flow was increased to approximately 14,000 cubic feet per minute. The cowling flaps were then unsealed and the air flow was increased to approximately 21,000 cubic feet per minute, which was sufficient for the engine, carburetor, and oil cooler. The cowling drag coefficient of 0.0012 measured for this arrangement is the lowest that has been obtained in Langley full-scale-tunnel tests of cowlings for radial air-cooled engines. Pressure measurements over the cowling indicate that the critical Mach number is 0.74. The dimensions of the annular-inlet cowling with spinner B are given in figure 4.

CONFIDENTIAL

Spinners		
x	y	y'
0	0	0
5	1.20	1.45
1	1.72	2.00
2	2.49	2.95
4	3.85	4.50
6	4.93	5.73
8	5.80	6.70
12	7.21	8.20
16	8.33	9.38
20	9.20	10.28
24	9.80	10.92
28	10.22	11.42
48	11.97	13.57

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

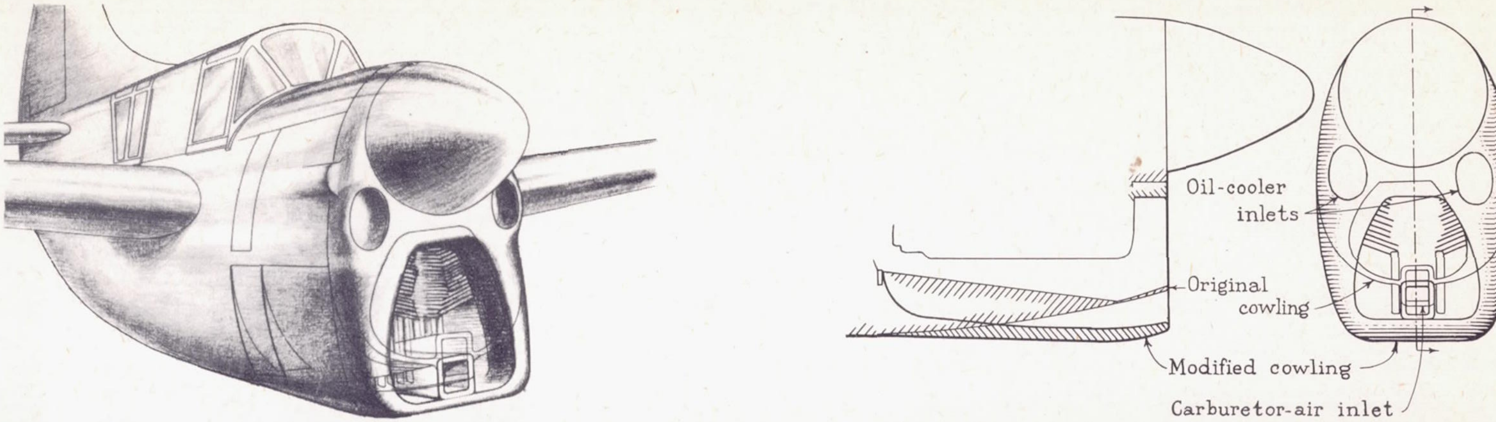


Cowling		
x	y_i	y_o
0	1.05	1.05
.125	.65	1.60
.25	.50	1.85
.50	.32	2.20
1.0	.12	2.65
2.0	0	3.40
3.0	.04	4.00
4.0	.13	4.55
5.0	.30	5.04
20.0	2.35	9.75

Figure 4.- Annular-inlet cowling with spinners A and B on airplane 1. All dimensions are given in inches.

CONFIDENTIAL

CONFIDENTIAL

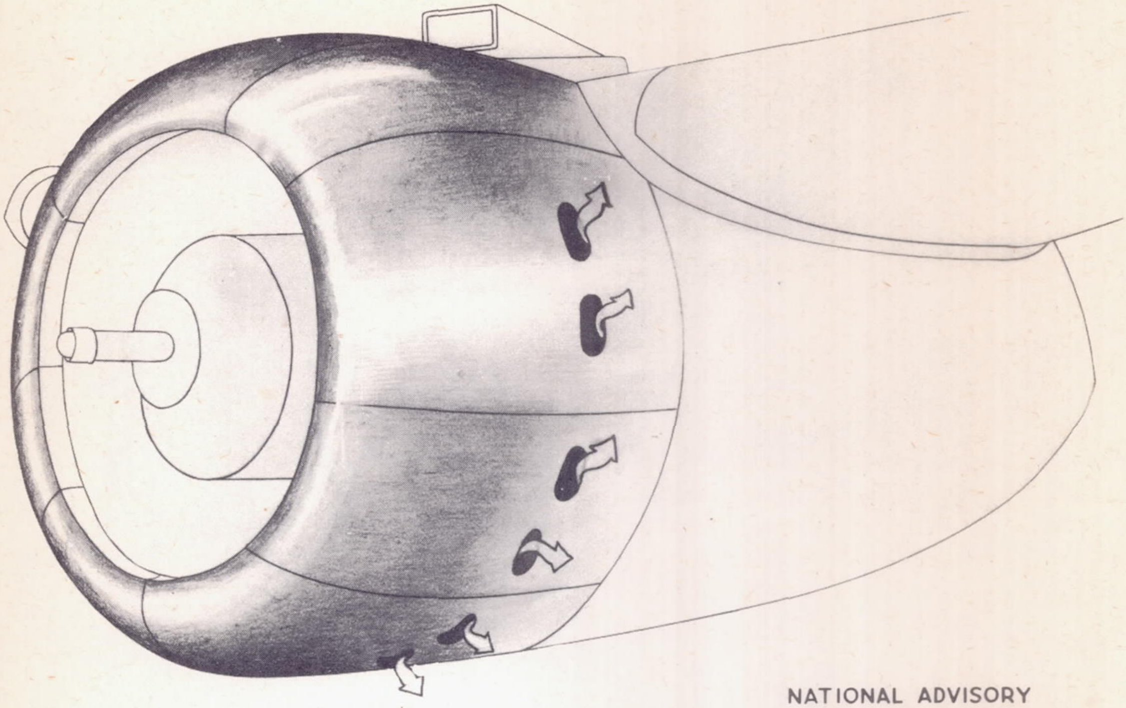


NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 5.- Cowling modification on airplane 2.

Flight tests showed that the inline air-cooled engine of airplane 2 did not cool satisfactorily in any flight attitude in the original condition. Tests in the Langley full-scale tunnel revealed that losses in the cooling system were excessive because of restricted inlet and outlet openings. The inlet was accordingly lowered and its area increased from 188 square inches to 241 square inches and additional outlet openings of 75 square inches were installed on each side of the cowling. These modifications increased the power-on inlet total pressure 25 percent in the climb attitude, principally because the inlet was lowered into a region of higher slipstream velocity. In addition, the average total pressure in front of the engine cylinders was increased. The drag coefficient with propeller removed was decreased 0.0004 by the cowling modification. This reduction is attributed mainly to the improved shape of the cowling lip and the greater efficiency of the internal flow.

CONFIDENTIAL



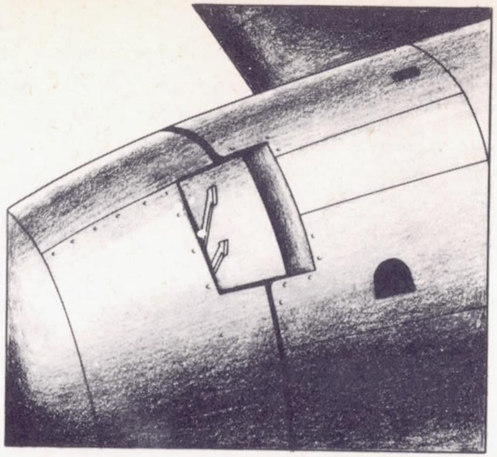
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0041
ΔV, 13 mph

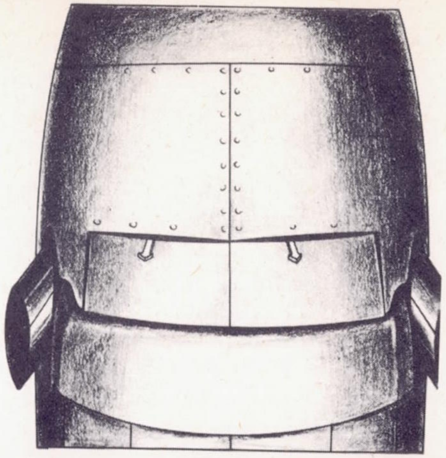
Figure 6.- Original cowling on airplane 3.

Some makeshift methods of controlling the air-flow quantity have been found to cause excessive drag. On airplane 3, for example, the designers cut eight holes, each with an area of 12.5 square inches, in the periphery of the cowling just behind the cylinder baffles in order to remedy unsatisfactory cooling of the engine in the climb condition. Tests by the Army and the manufacturer indicated that the cooling problem was not remedied for the climb condition and the flow disturbances caused by the holes resulted in an increase in drag coefficient of 0.0041 for the cowlings of the two engines, which corresponds to a decrease in the airplane high speed of about 13 miles per hour.

CONFIDENTIAL



Upper cowling flap



Lower cowling flaps

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0004
ΔV, 2 mph

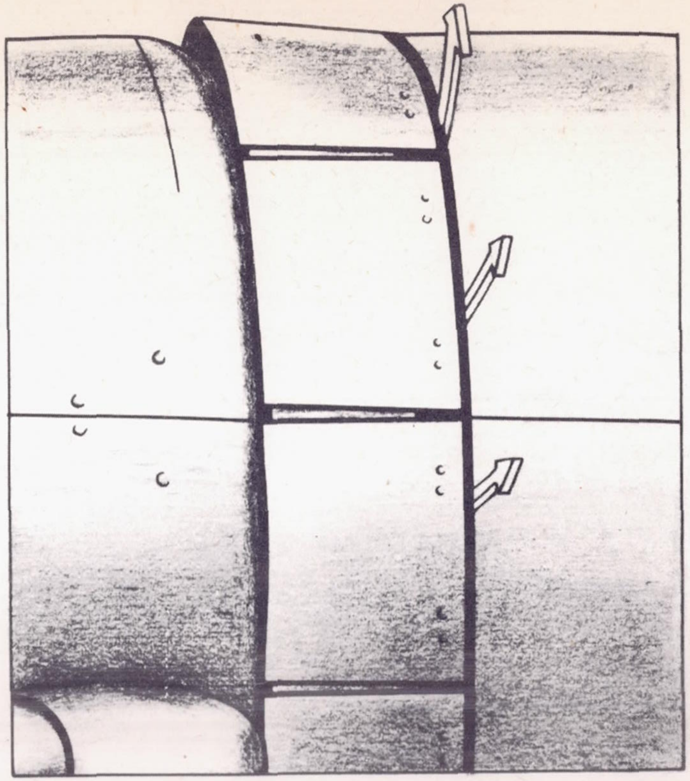
(a) Airplane 6.

Figure 7.- Cowling-flap-gap drag.

Drag increases were measured when the doped-tape seals were removed from the gaps at the hinge line of the closed cowling flaps of airplanes 6, 8, and 10. The arrows show points of leakage that disturbed the external flow and resulted in an increase of drag. More complete sealing or directing the air flow backward would tend to eliminate this drag increment.

CONFIDENTIAL

[redacted]



Cowling flap closed

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

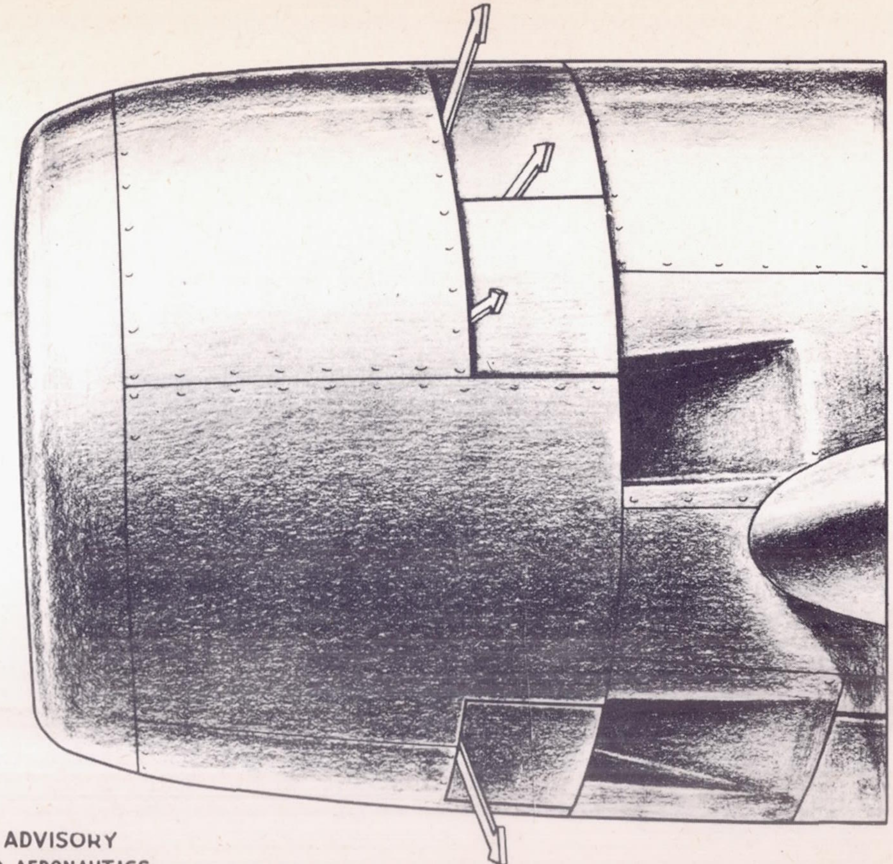
ΔC_D, 0.0005
ΔV, 3 mph

(b) Airplane 8.

Figure 7.- Continued.

[redacted]

[redacted]



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0005

ΔV, 3 mph

(c) Airplane 10.

Figure 7.- Concluded.

[redacted]

[redacted]

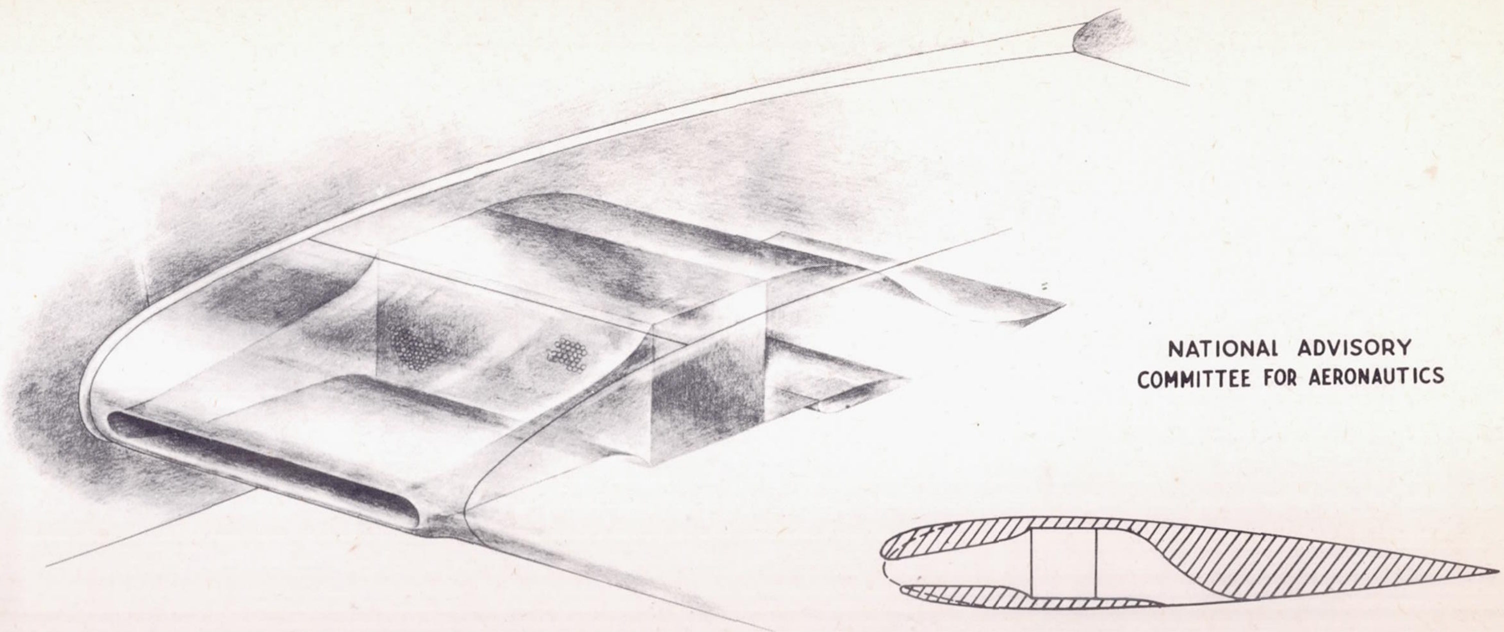
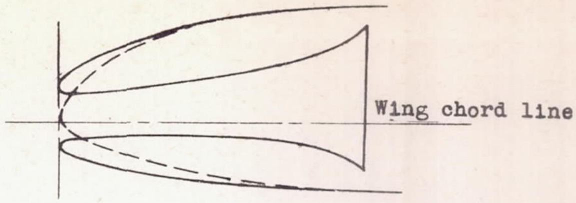
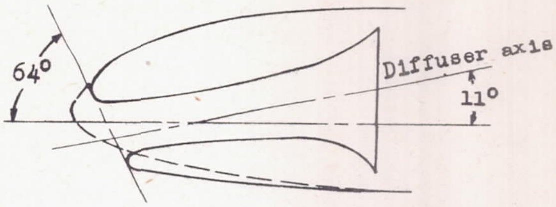


Figure 8.- General arrangement of wing-duct installation on airplane 7.

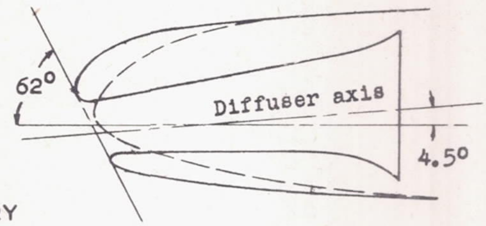
[redacted]



(a) Inlet 1.



(b) Inlet 5.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

(c) Inlet 4.

Inlet	C_L	ΔC_D	Q/V_o	$H - p_o$
1	0.12 .89	0.0006	0.56	$0.95q_o$ $.22q_o$
5	.12 .89	.0022	.56	$.86q_o$ $.87q_o$
4	.12 .89	[a].0011	[a].56	$.95q_o$ $.68q_o$

[a]Estimated.

Figure 9.- Representative inlet shapes tested on airplane 7.

The small sharp-lip inlet with the inlet plane perpendicular to and the diffuser axis parallel to the wing chord (inlet 1) showed the lowest drag at low lift coefficients. At high lift coefficients, the internal flow separated from the lower lip and resulted in a loss in pressure recovery at the face of the radiator. Inlet 5 (reference 4) was designed to obtain higher pressure recoveries at high lift coefficients. At low lift coefficients, however, the pressure recovery for inlet 5 was less than for inlet 1 because separation occurred just inside the upper lip. No separation occurred at high lift coefficients and the pressure recovery was higher with inlet 5 than with inlet 1. The drag of inlet 5 was the highest of all the inlets tested. Obviously, from the results obtained with inlets 1 and 5, a compromise inlet shape was necessary (inlet 4). Inlet 4 was the most satisfactory in consideration of high pressure recovery and low drag for a large range of flight conditions. When inlet lips are extended (inlet 4), the design should be made with due regard to the external shape. Since no drag data were available for inlet 4 at $Q/V_o = 0.56$, the drag increment given was estimated from available data at $Q/V_o = 0.70$.

CONFIDENTIAL

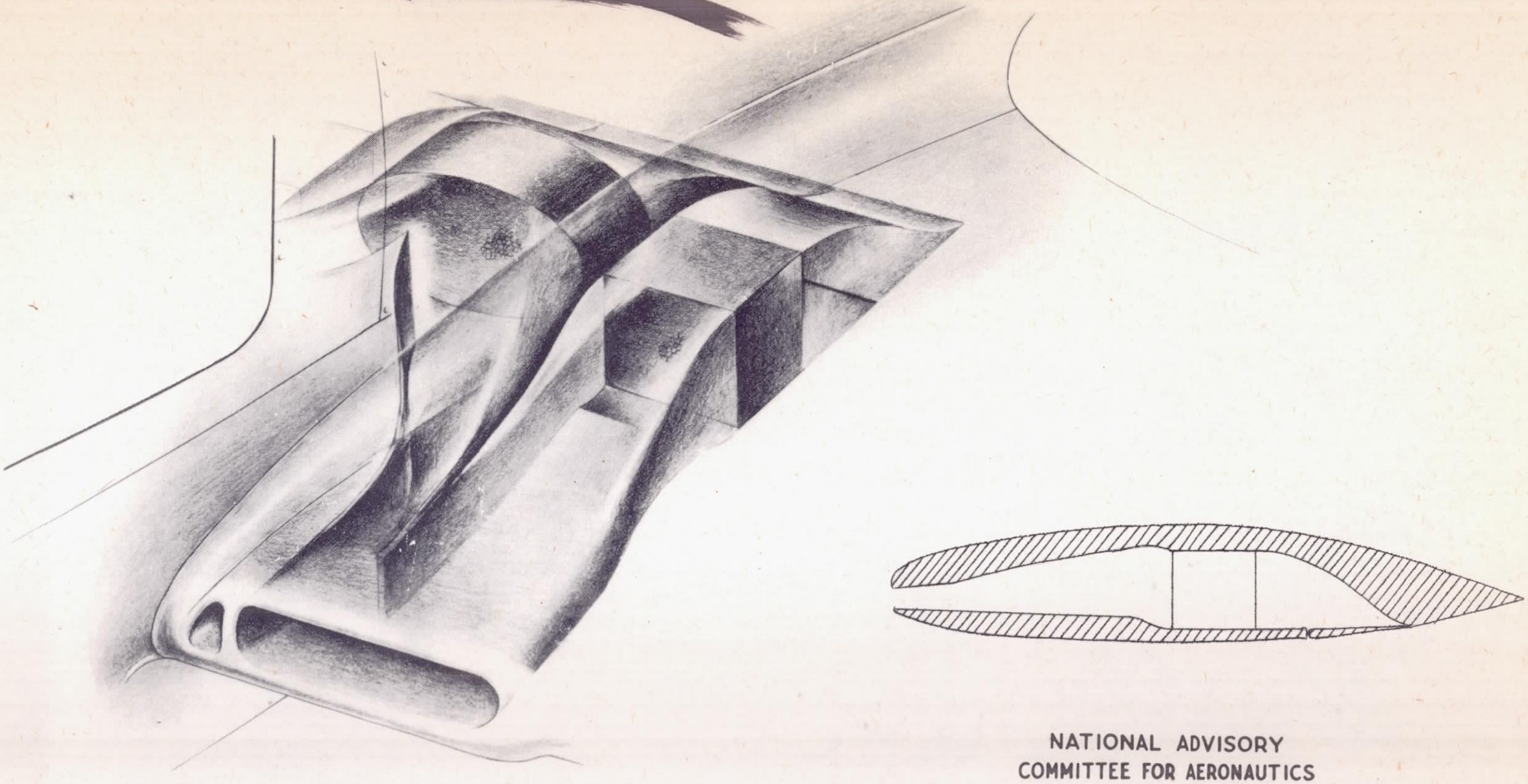
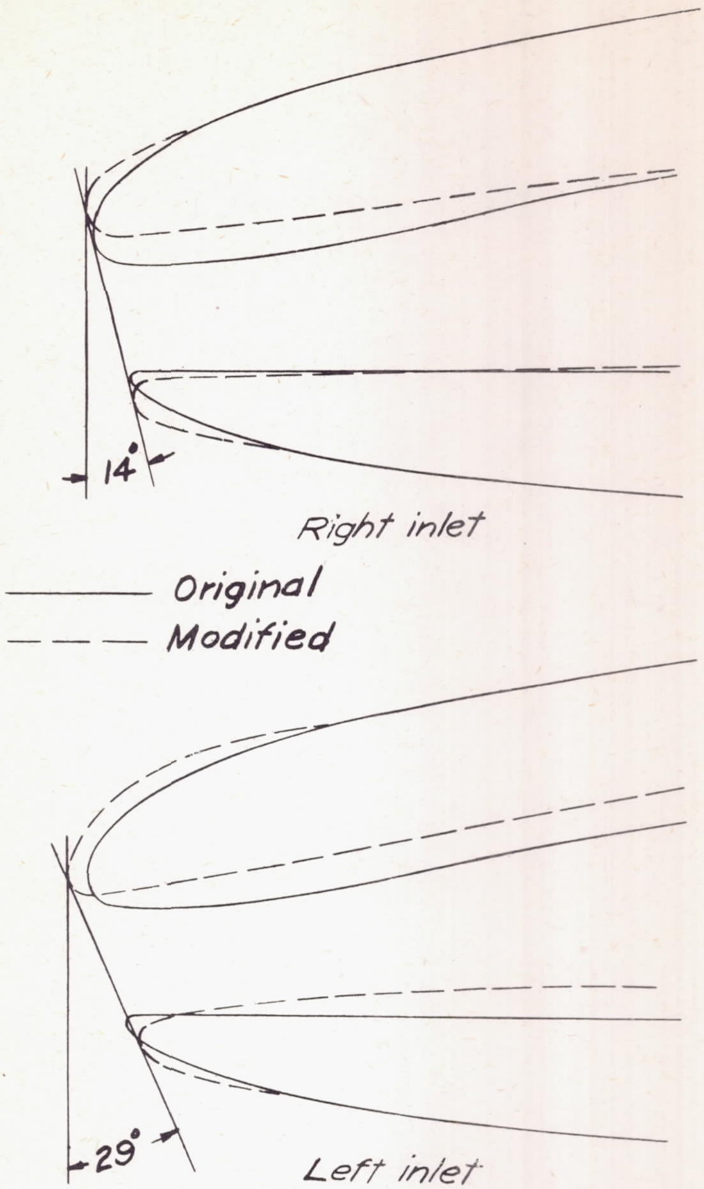


Figure 10.- Wing-duct inlet on airplane 11.

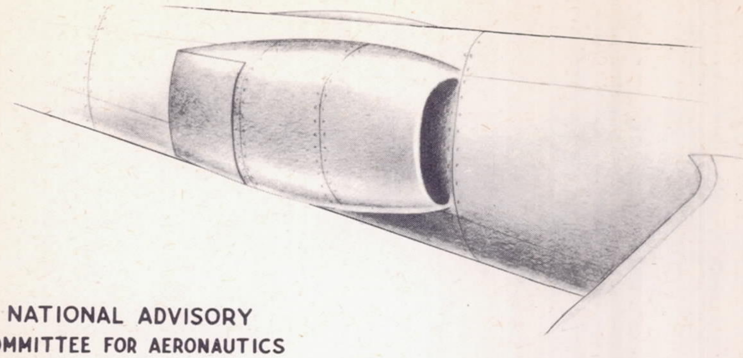
A drag-coefficient increment of 0.0013 was measured when the seals were removed from the wing-duct inlets and exits with the exit flaps at 0° for airplane 11 in the high-speed condition. Removing seals from holes in the top of the duct exits for flap-control push rods added an increment of 0.0004, which made the total-drag coefficient 0.0017 for the original installation with a large quantity of air flowing through the duct because of air leakage at the exit flap. Tests with the propeller operating showed that serious losses in total-pressure recovery occurred as a result of the misalinement of the duct lips to the air stream caused by the slipstream rotation. In order to remedy this condition, modified inlets were installed (fig. 11) with the plane of the inlet on the side of the upgoing propeller blade tilted 15° farther downward than the plane of the inlet on the side of the downgoing propeller blade. A further modification, which consisted of an increase in area of the right and left inlets from 55 to 73 square inches, was made to lower the inlet-velocity ratio. For the high-speed condition, with the exit flaps at 0°, the modified inlets decreased the drag coefficient 0.0005 and increased the total pressure at the faces of the radiators 15 percent. The cooling was improved for both the high-speed and climb conditions with the modified inlets.

CONFIDENTIAL



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

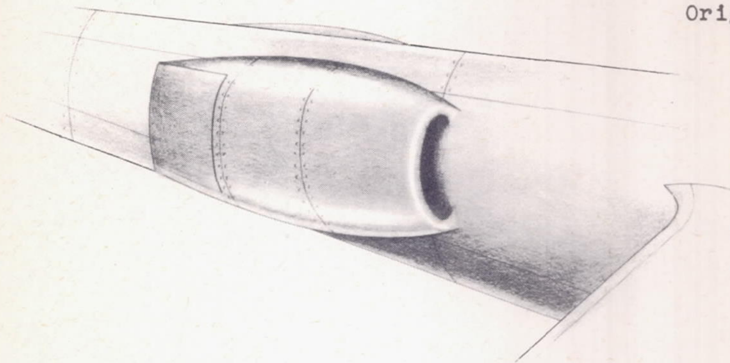
Figure 11.- Sections at centers of original and modified wing-duct inlets on airplane 11.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0021
ΔV, 12 mph

Original coolant-duct inlet



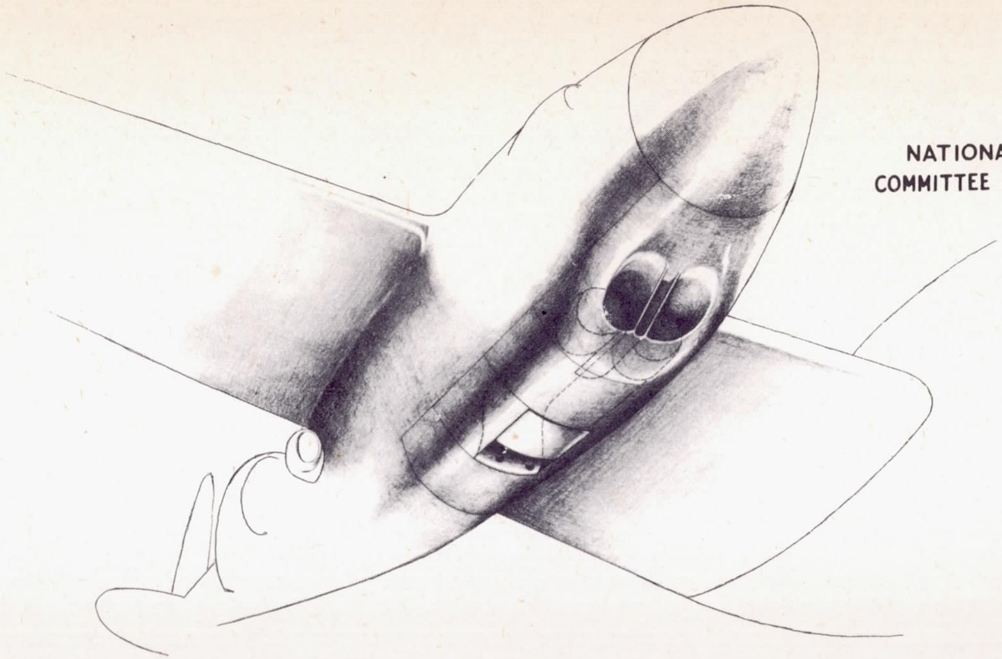
ΔC_D, 0.0024
ΔV, 14 mph

Revised coolant-duct inlet

(a) Coolant ducts.

Figure 12.- Duct installations on airplane 4.

The drag coefficient of the experimental airplane 4 with the four original coolant radiator ducts installed and with the outlet flaps open (exit seals removed) for the high-speed condition was 0.0021 greater than for the airplane with the ducts removed. Revised ducts for the production airplane were installed with a smaller inlet area and higher inlet-velocity ratio. The increase of drag coefficient due to the revised ducts was 0.0024 but the air-flow quantity was increased 9 percent as compared with that of the original duct. With the revised inlets and with the outlet flaps full open, however, the air-flow quantity was 6 percent less than with the original ducts for the same condition and the drag was 0.0051 as compared with 0.0043 for the original ducts. Since the ducts are in a region of low-energy air, sufficient cooling cannot be obtained with low drag.



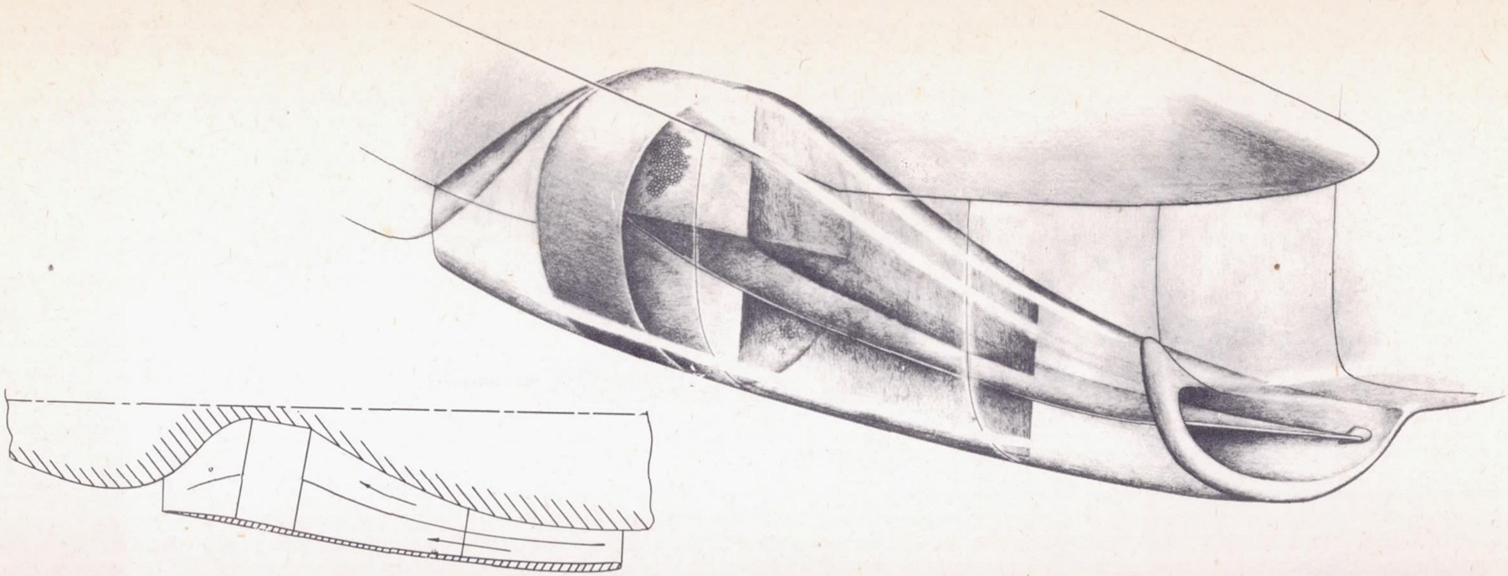
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0008
ΔV, 4 mph

(b) Oil-cooler installation.

Figure 12.- Concluded.

The oil-cooler air inlet on airplane 4 is set at such a high oblique angle to the direction of the air stream that the flow tends to overrun the inlet. For the airplane in the high-speed attitude, the average total-pressure recovery at the faces of the oil coolers was only $0.33q_0$. Extending the lower lip of the inlet forward in order that the plane of the inlet will be more nearly normal to the local air flow should result in the recovery of most of the available total pressure. The increment of drag coefficient given on the figure is the difference in the drag of the airplane with both the inlets and outlets sealed and unsealed.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

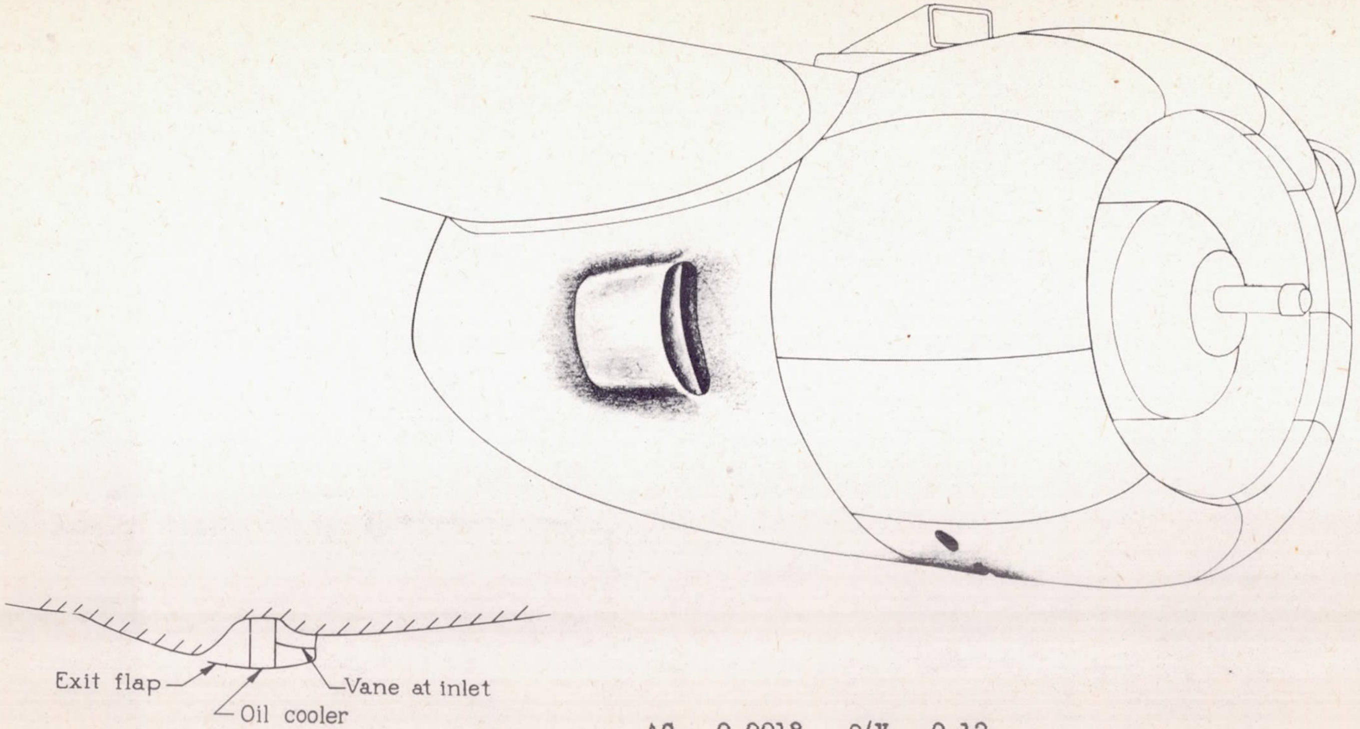
ΔC_D, 0.0004
ΔV, 2 mph

Figure 13.- Guide vanes installed in the rear underslung duct of airplane 7.

Vanes were installed in the rear underslung duct of airplane 7 to reduce the pressure losses at the radiator face as a result of separation caused by a thick boundary layer at the inlet. The drag coefficient was 0.0004 less with the guide vanes installed in the diffuser and the outlet than without the vanes. In addition, the pressure recovery at the radiator face was increased by the vane installation from $0.69q_o$ to $0.83q_o$ at $\alpha_T = 0.2^o$ and from $0.84q_o$ to $0.92q_o$ at $\alpha_T = 10.4^o$.

CONFIDENTIAL

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



ΔC_D, 0.0018 Q/V_o, 0.12

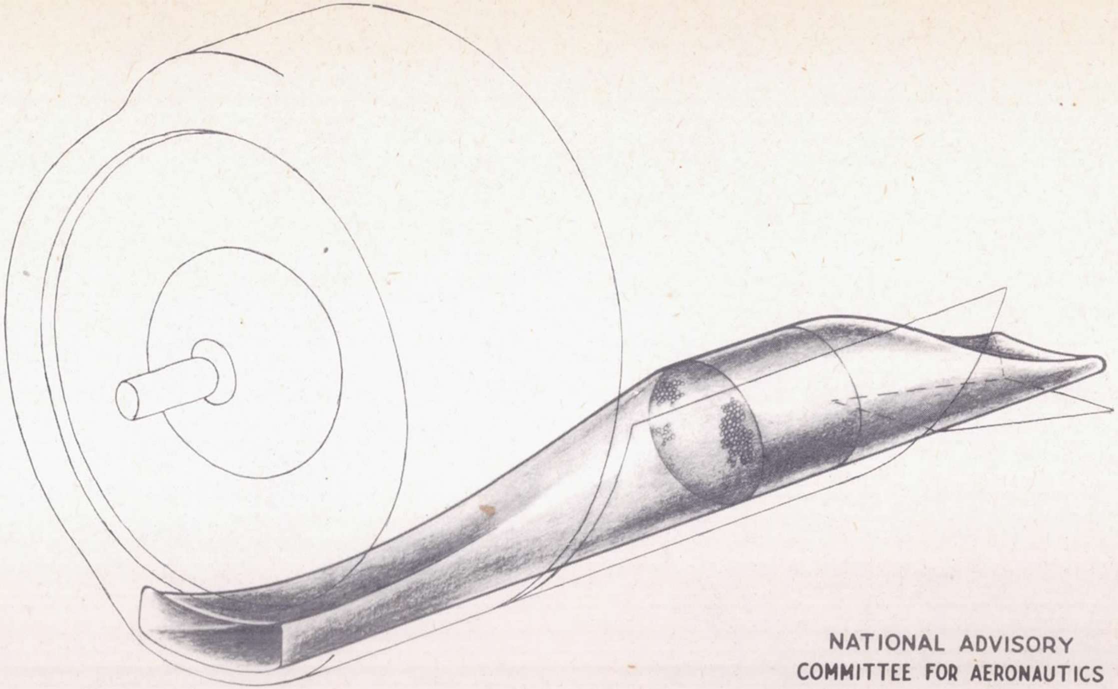
ΔV, 7 mph $H - p_o$, $0.40q_o$

(a) Original duct inlet.

Figure 14.- Oil-cooler installation on airplane 3.

The total-pressure recovery measured at the face of the oil cooler of airplane 3 for the high-speed condition was only $0.40q_o$. This low recovery of total pressure is attributed to the thick boundary layer at the duct inlet. The drag due to ducts on both nacelles with the outlets open for the high-speed condition was 0.0018 greater than with the ducts removed. The Langley full-scale-tunnel modification to improve this installation is described in figure 14(b).

CONFIDENTIAL



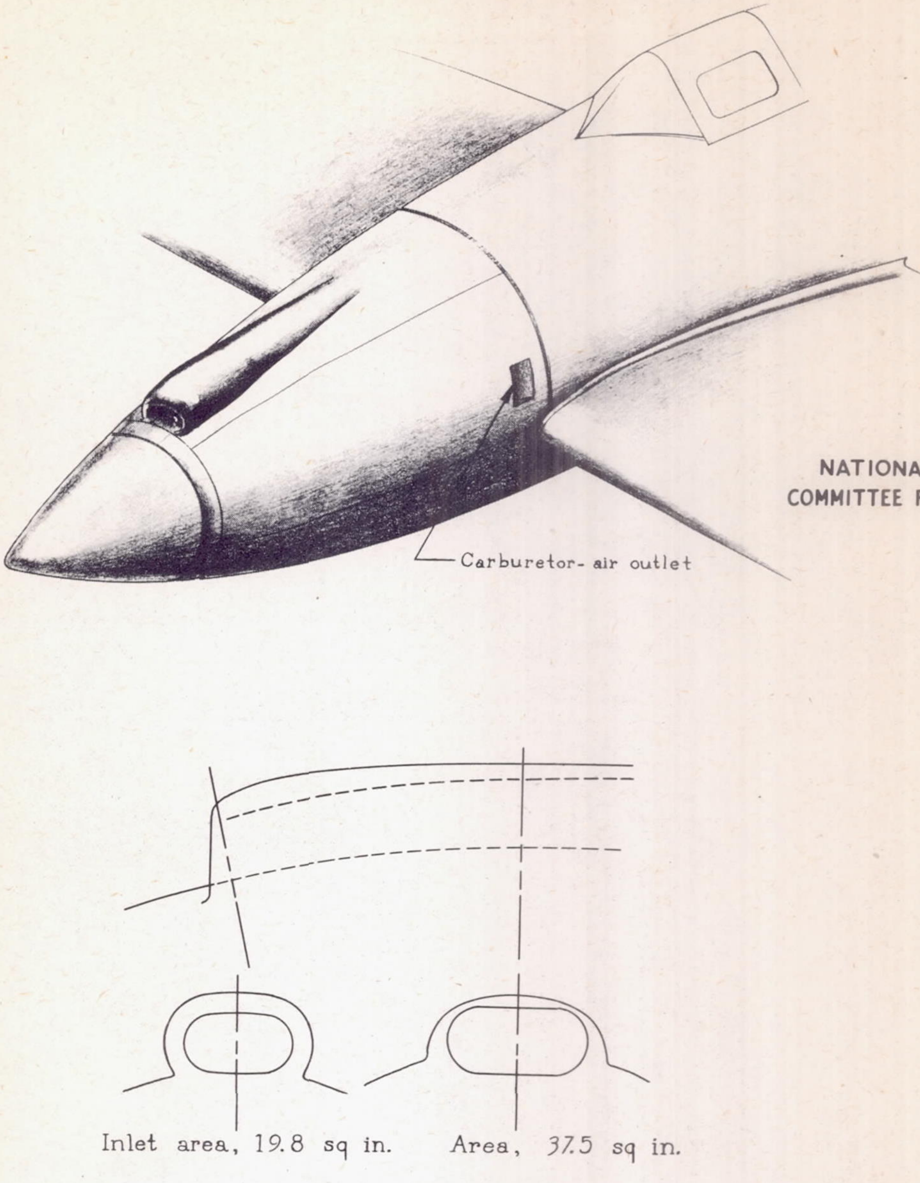
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0010 Q/V_o, 0.13
ΔV, 5 mph $H - p_o$, $0.95q_o$

(b) Modified cowling and ducts.

Figure 14.- Concluded.

A new oil-cooler duct was constructed for airplane 3 having its inlet flush with the face of the cowling and a gradually expanding diffuser. The total-pressure recovery at the face of the oil cooler was increased to $0.95q_o$ and the drag coefficient reduced by 0.0008 as a result of this modification.



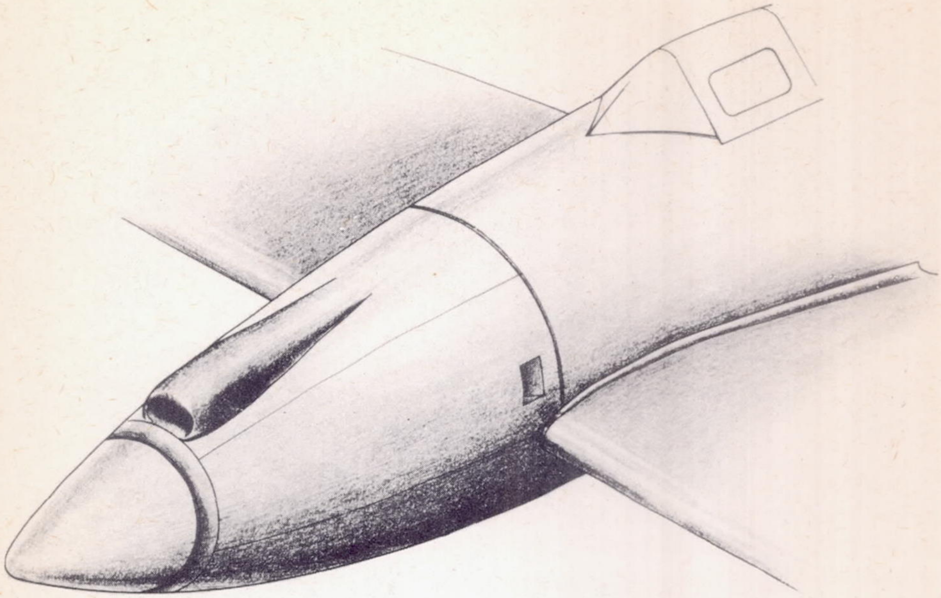
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

V_1/V_o, 0.49 Ram, $0.91q_o$
Q/V_o, 0.07 ΔC_D, 0.0002

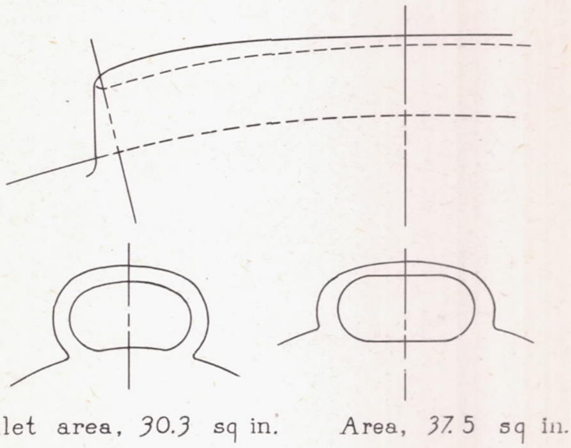
(a) Scoop 1.

Figure 15.- Carburetor-air scoops on airplane 7.

The scoops tested on airplane 7 were of conventional protruding design. The inlet areas were varied for the different scoops and slight variations were also made in the external shapes of the scoops. The best results were obtained at inlet-velocity ratios between 0.4 and 0.5. At inlet-velocity ratios below about 0.3, boundary-layer separation occurred at the inlets. The increment of drag is the difference in drag of the airplane with and without the carburetor-air system and includes the drag due to flow through the outlet duct and the outlet losses.



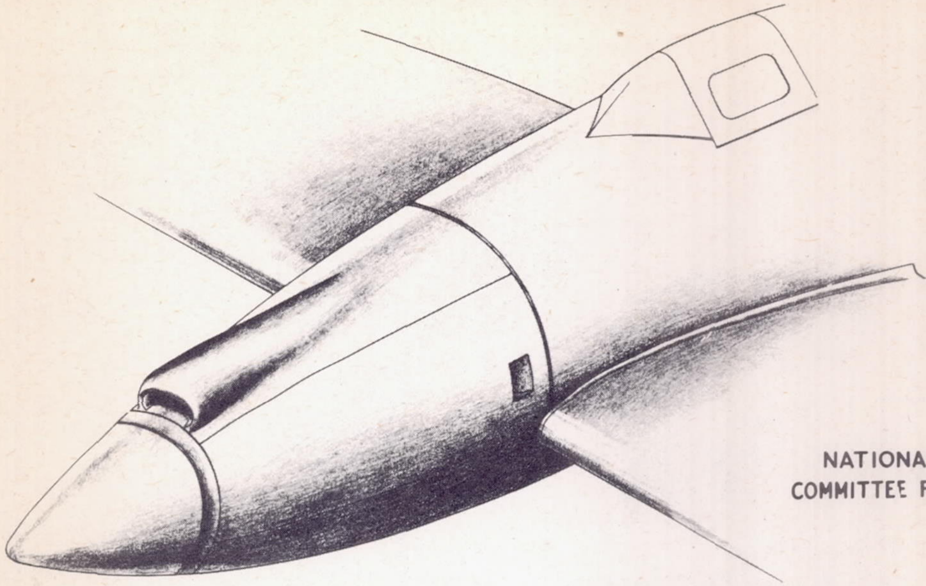
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

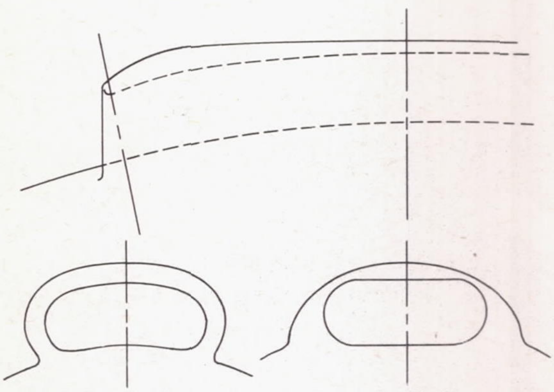


V_1/V_o, 0.32 Ram, $0.91q_o$
Q/V_o, 0.07 ΔC_D, 0.0002

(b) Scoop 2.

Figure 15.- Continued.

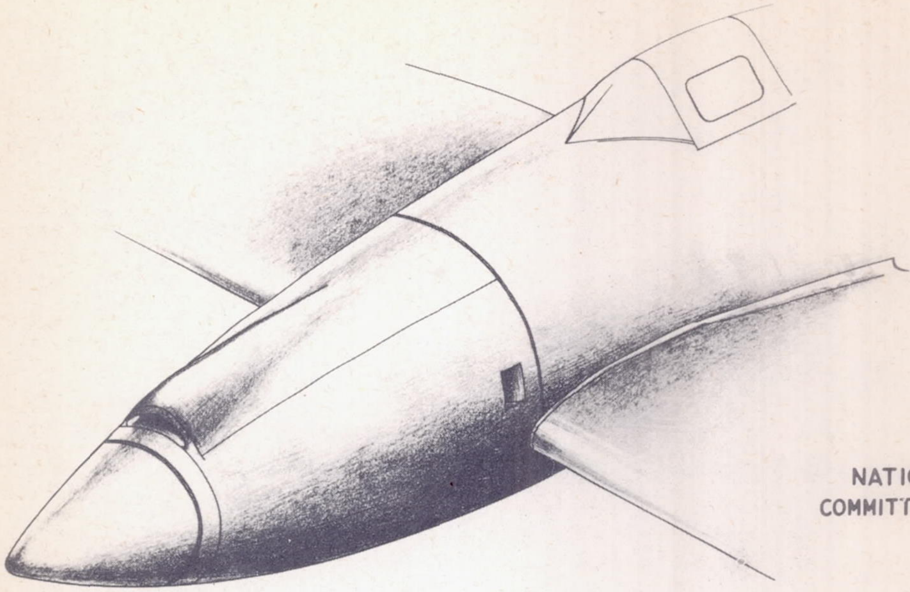


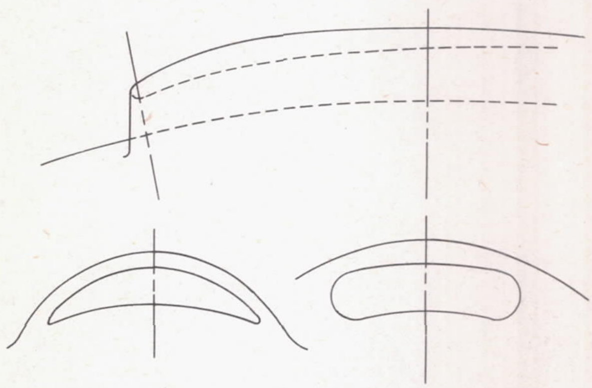


V_1/V_o, 0.33 Ram, 0.87q_o
Q/V_o, 0.10 ΔC_D, 0.0006

(c) Scoop 3.

Figure 15.- Continued.



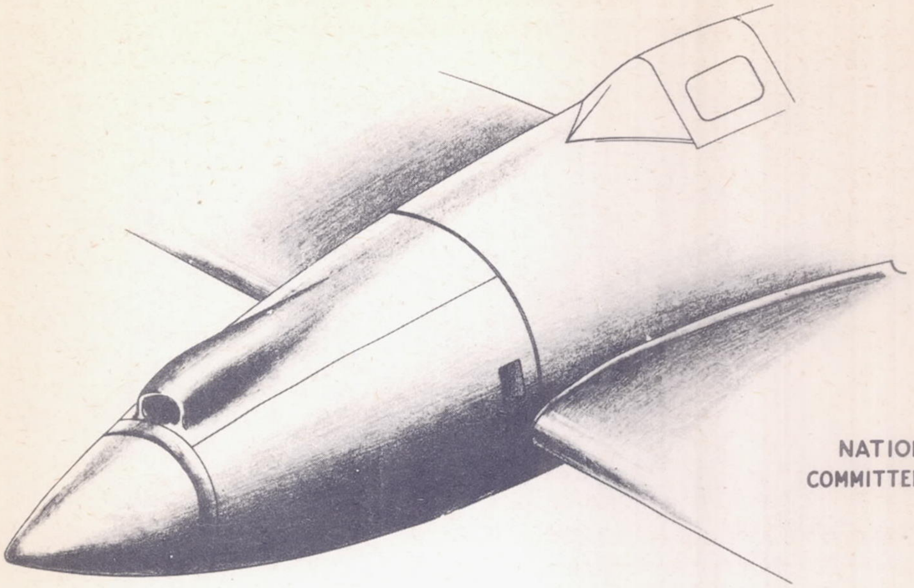


Inlet area, 32.7 sq in. Area, 40.9 sq in.

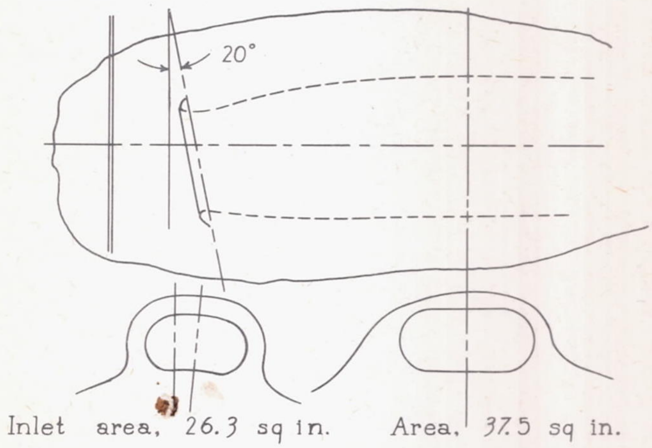
V_1/V_o, 0.27 Ram, $0.88q_o$
Q/V_o, 0.06 ΔC_D, 0.0003

(d) Scoop 4.

Figure 15.- Concluded.



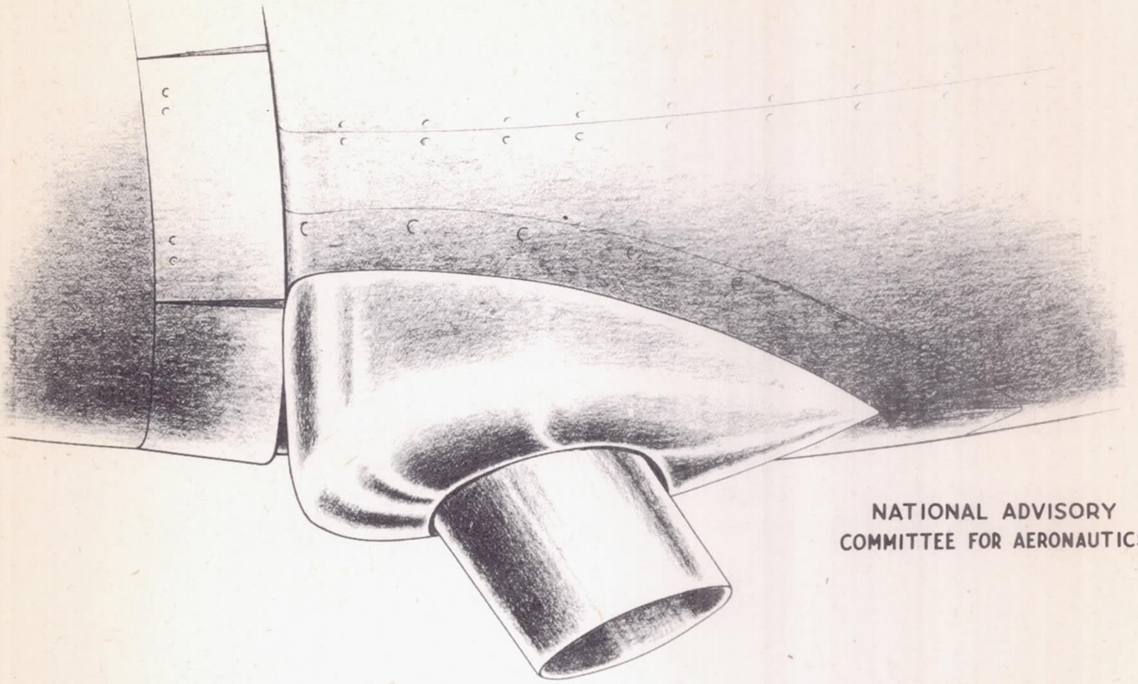
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



V_1/V_0, 0.37 Ram, $0.91q_0$
Q/V_0, 0.07 ΔC_D, 0.0003

Figure 16.- Carburetor-air scoop 5 on airplane 7.

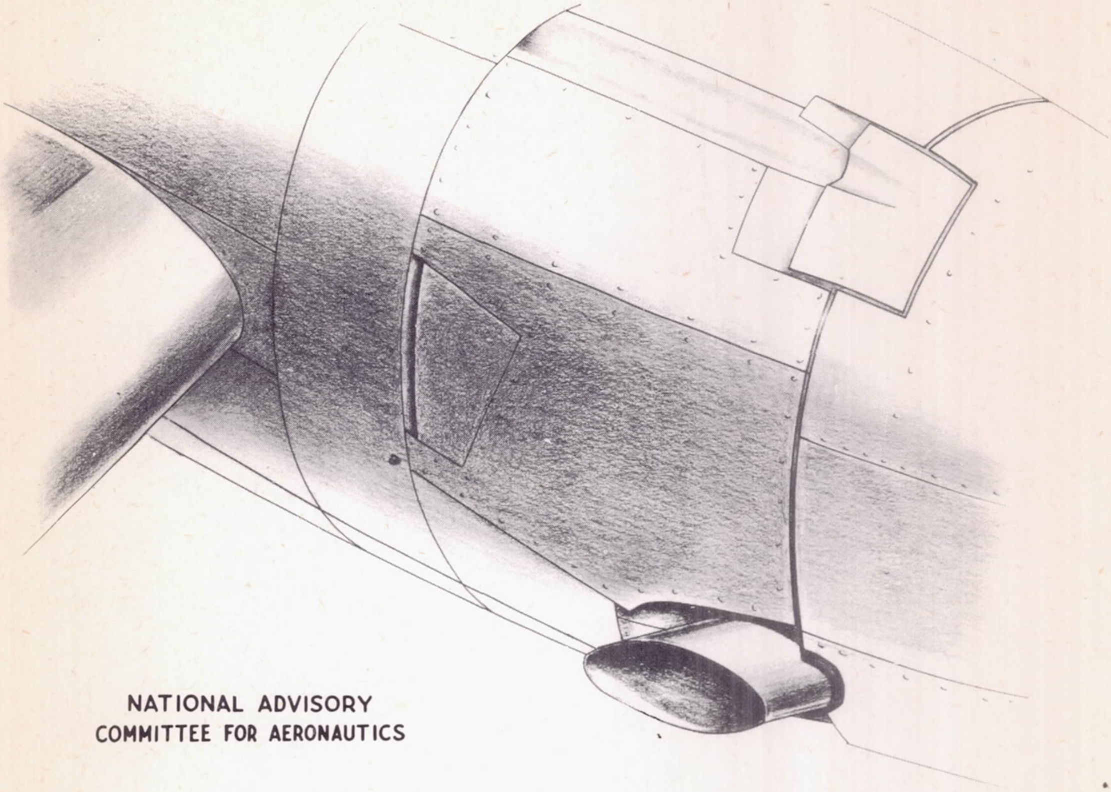
Propeller-operating tests were made with scoop 5 installed on airplane 7 to determine the advantage of turning the inlet directly into the slipstream. An increase in ram of 3 percent of the free-stream dynamic pressure was measured as a result of turning the scoop for the high-speed propeller-operating condition. The effect on the drag coefficient of turning the scoop was negligible.



ΔC_D, 0.0021
ΔV, 9.5 mph

Figure 17.- Exhaust-stack drag on airplane 8.

The large protrusion and the air leakage around the large-bore stovepipe exhaust stacks on airplane 8 account for a drag-coefficient increment of 0.0021. Engine-operating tests at low speed were made both with the original exhaust stacks installed and with individual jet exhaust stacks installed. The tests indicate that the increase in thrust due to the individual jet exhaust stacks would increase the airplane speed by approximately 13 miles per hour over the speed with the original exhaust stacks installed. This thrust increase includes the difference in drag between the original exhaust stacks and the individual jet exhaust stacks. Calculations based on the methods of reference 8 indicate that with the use of optimum-size jet exhaust stacks a further increase of 3 miles per hour would be possible.

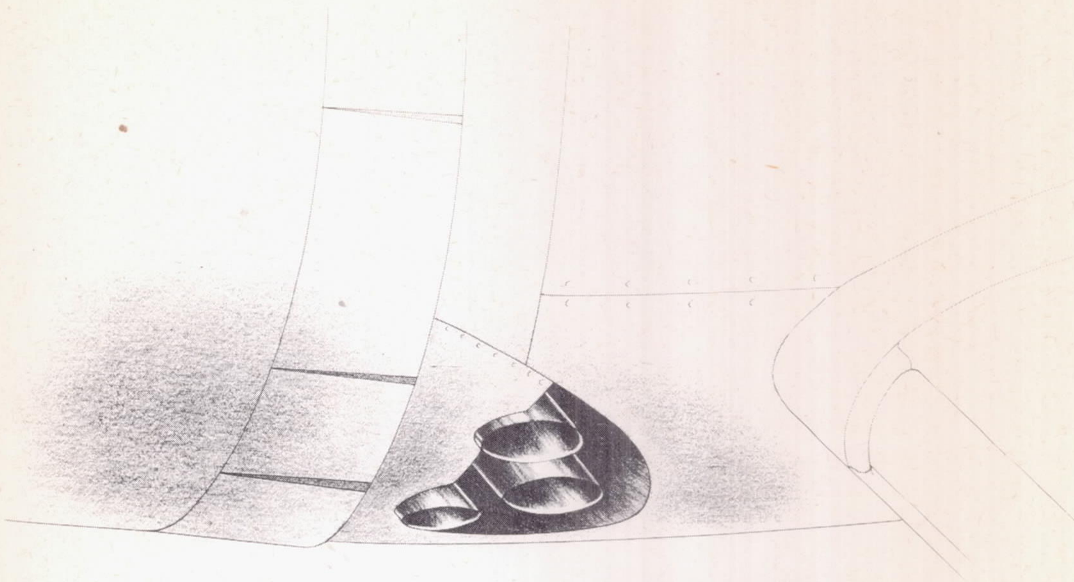


NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0008
ΔV, 3 mph

Figure 18.- Exhaust-stack drag on airplane 6.

The installation of this large-bore exhaust stack with large leakage gaps around the stack increased the drag by 0.0008. The use of stovepipe exhaust stacks of this type and of the type used on airplane 8 (fig. 17) should be avoided because of the large form drag.

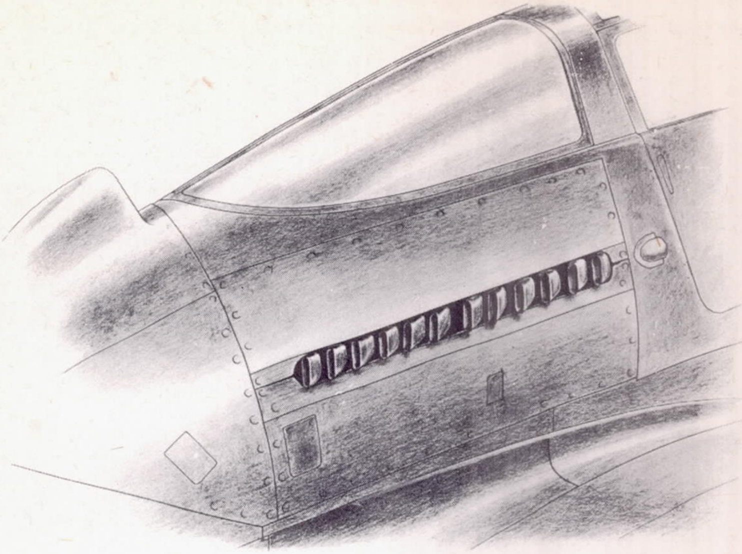


NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0010
ΔV, 6 mph

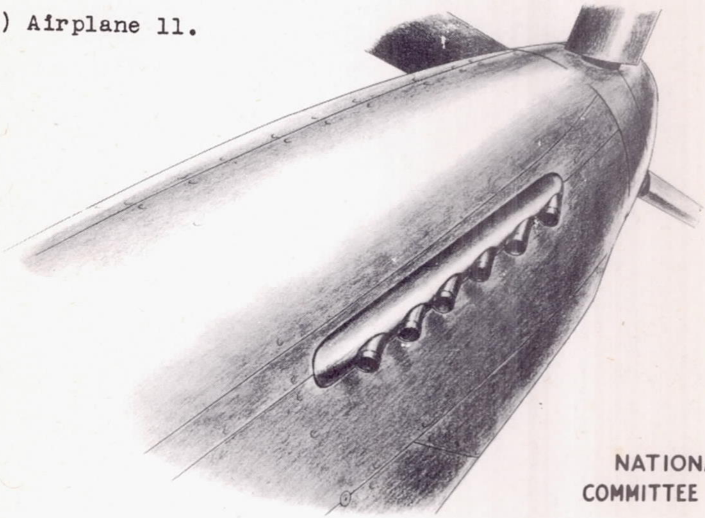
Figure 19.- Exhaust-stack drag on airplane 9.

Removing the seal from the exhaust opening of airplane 9 increased the drag by 0.0010. The form drag of the installations shown in figures 17 and 18 has been avoided in this design; however, the large amount of air leakage from the compartment behind the engine out through the large opening around the exhaust stacks accounts for the excessive drag of the installation. Some of this drag would be reduced by directing the leakage flow rearward. Much larger gains can be obtained by the use of individual jet exhaust stacks.



ΔC_D, 0.0005
ΔV, 3 mph

(a) Airplane 11.



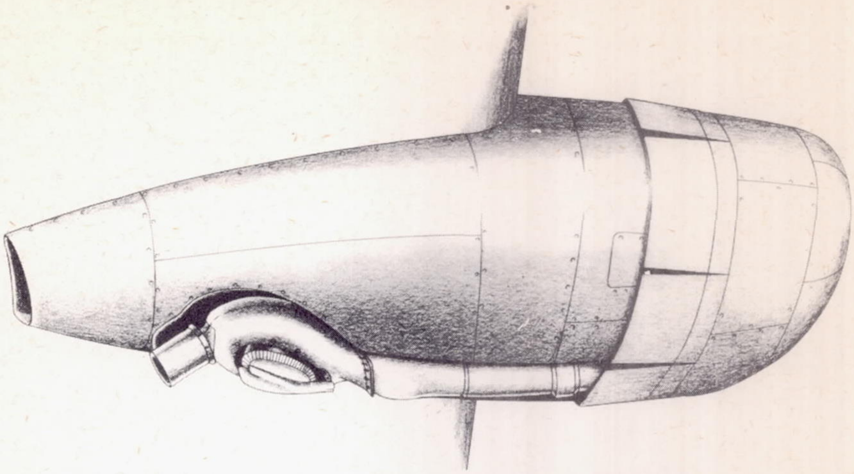
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0007
ΔV, 4 mph

(b) Airplane 12.

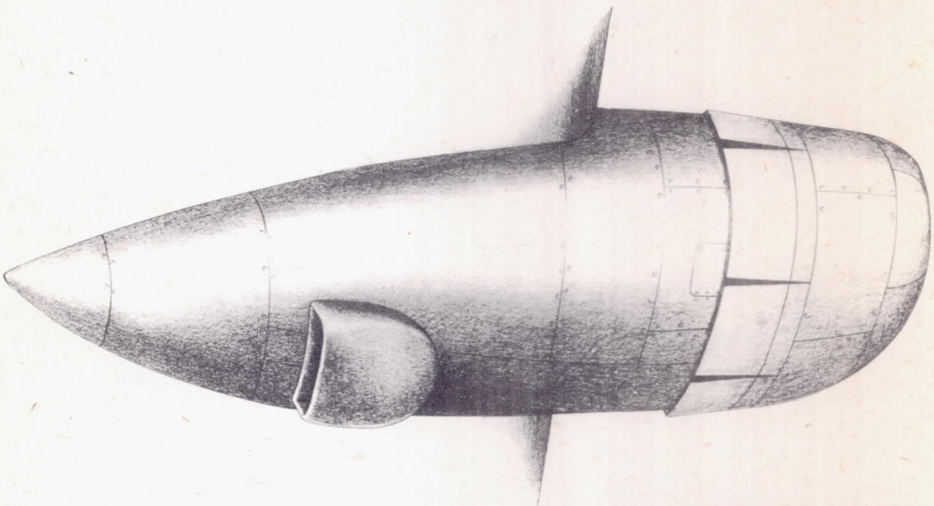
Figure 20.- Exhaust-stack drag on airplanes 11 and 12.

Removing the sealed metal fairings that enclosed the exhaust stacks of airplanes 11 and 12 increased the drag coefficient 0.0005 for airplane 11 and 0.0007 for airplane 12. These exhaust stacks are relatively good installations.



ΔC_D, 0.0040
ΔV, 11 mph

(a) Original installation.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

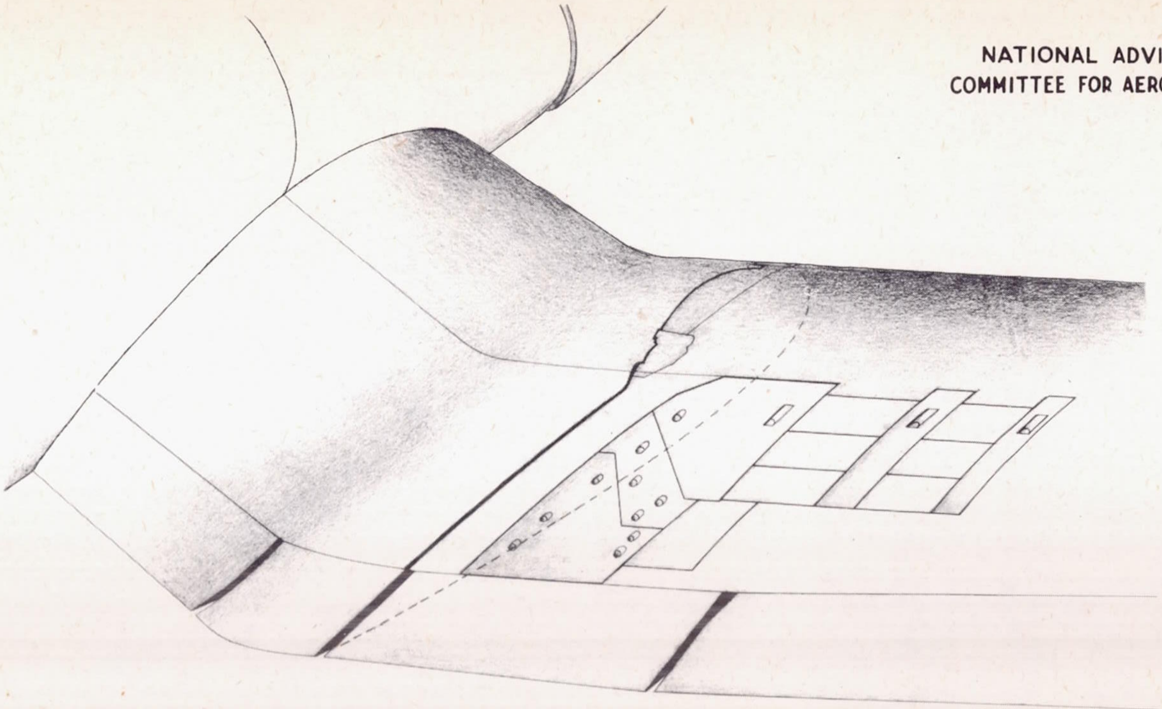
ΔC_D, 0.0027
ΔV, 8 mph

(b) Submerged installation.

Figure 21.- Turbosupercharger drag on airplane 5.

An increment of drag coefficient of 0.0040 was measured for the exposed supercharger of the original installation of airplane 5 (fig. 21(a)). Submerging the supercharger and sealing the opening at the end of the nacelle as shown in figure 21(b) decreased the drag coefficient of the installation to 0.0027. For the propeller-operating condition, the difference in drag will be much greater because the submerged installation will direct the exhaust gases rearward. The submerged installation would require shroud cooling. The drag increments are given for four nacelles and are based on the airplane wing area.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

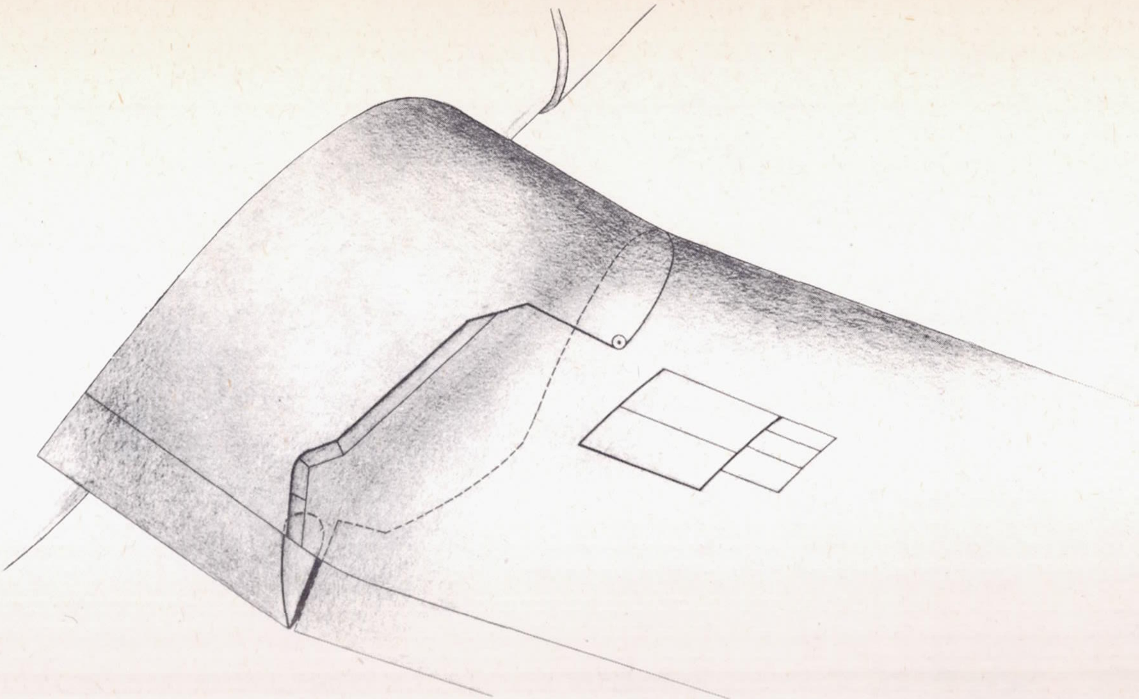


ΔC_D, 0.0012
ΔV, 6 mph

Figure 22.- Effect on wing drag of irregularities and leakage on airplane 9.

The unusually large number of cover plates, access doors, butt joints, and air-leakage points on the wing of airplane 9 caused a drag increase of 0.0012. Most of this drag could have been avoided by better fitting and elimination of air leakage.

CONFIDENTIAL



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

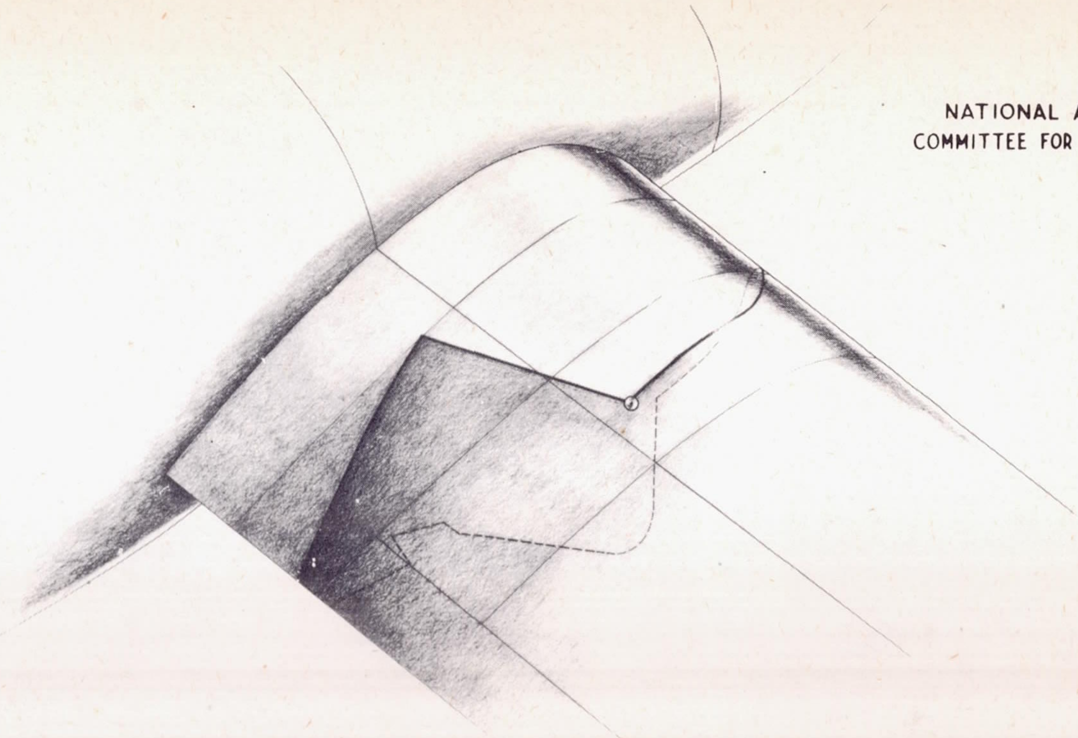
ΔC_D, 0.0007
ΔV, 4 mph

Figure 23.- Effect on wing drag of irregularities and leakage on airplane 10.

An increase in drag coefficient of 0.0007 was measured when the doped-tape seals were removed from the gaps at the wing-fold joint and gun-access and ammunition doors. Considerable leakage drag can be eliminated by sealing these gaps.

CONFIDENTIAL

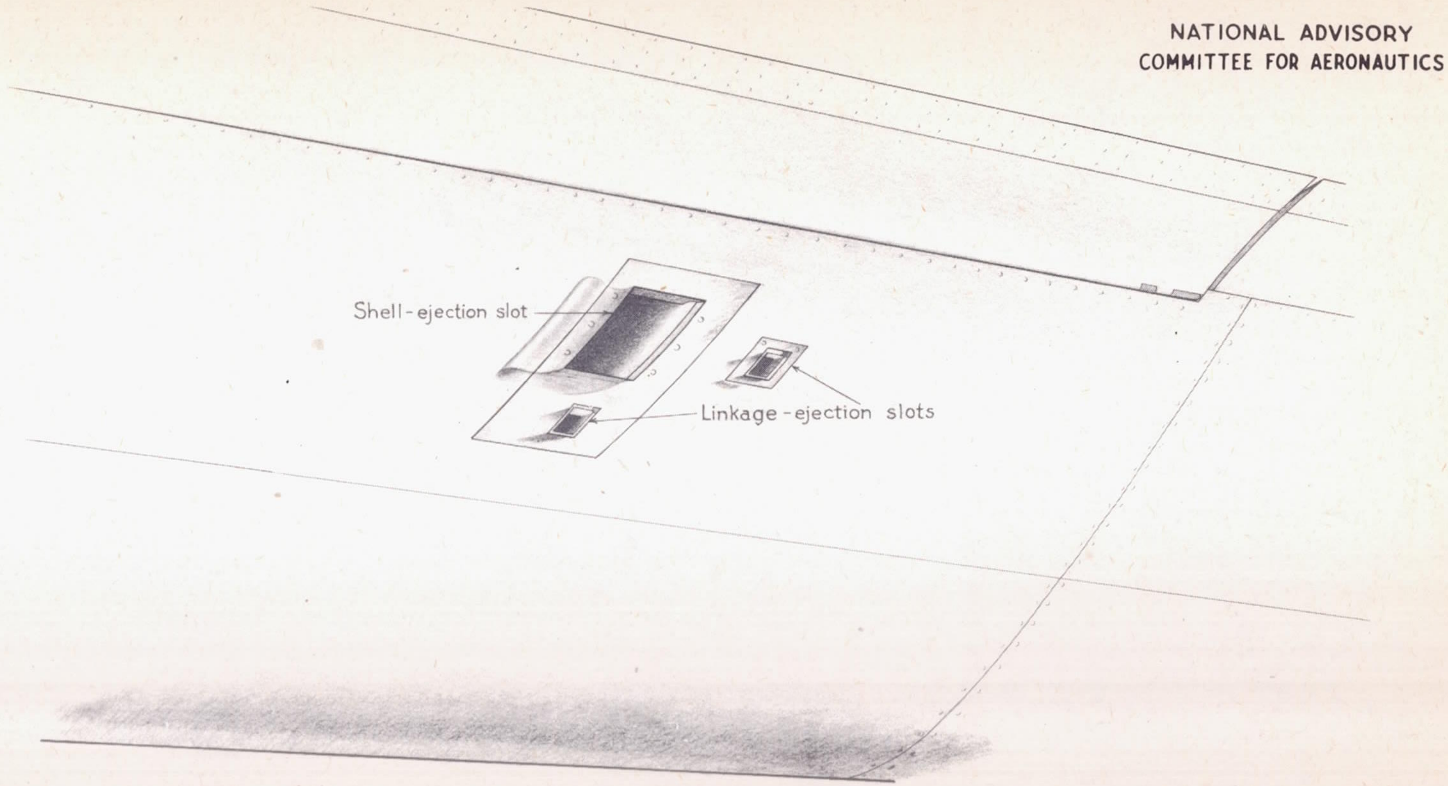
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



ΔC_D, 0.0004
ΔV, 2 mph

Figure 24.- Effect on wing drag of leakage on airplane 6.

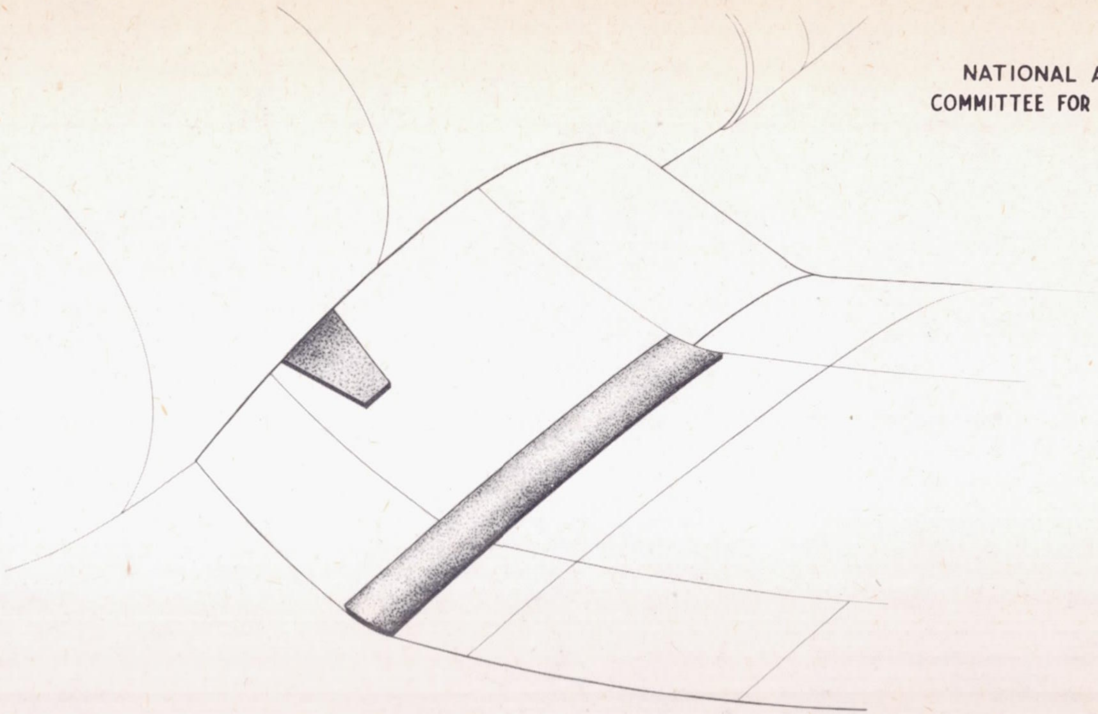
An increase in drag coefficient of 0.0004 was measured when the doped-tape seals were removed from the wing-fold joints on airplane 6.



ΔC_D, 0.0005
ΔV, 3 mph

Figure 25.- Effect on wing drag of irregularities and leakage on airplane 12.

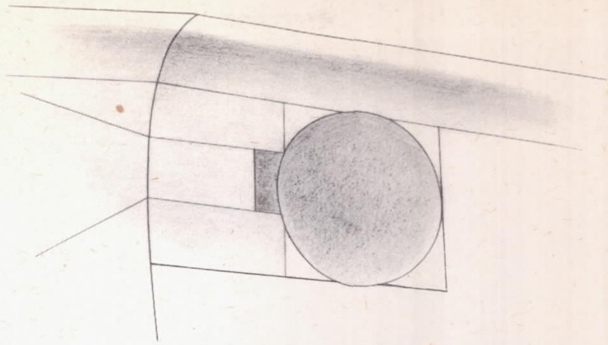
Air entered the large shell- and linkage-ejection slots on the under surface of the wing of airplane 12 and leaked through the ammunition doors on the upper surface, thus increasing the drag. Sealing the slots when the guns are not in use or sealing the ammunition doors would eliminate this drag increment.



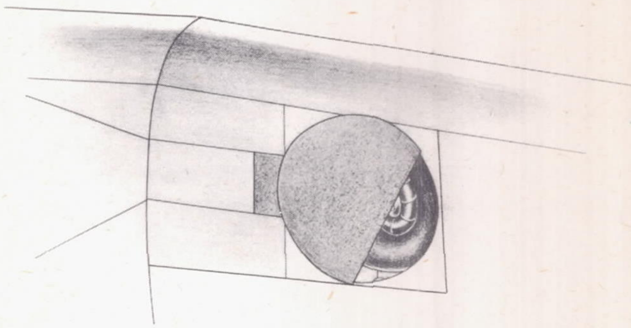
ΔC_D, 0.0010
ΔV, 5 mph

Figure 26.- Effect on wing drag of sanded walkway on airplane 9.

The sanded wing walkways, which protruded about 1/4 inch above the wing surface of airplane 9, were responsible for a drag increase of 0.0010. These walkways are a source of excessive drag and should be eliminated on high-speed airplanes.

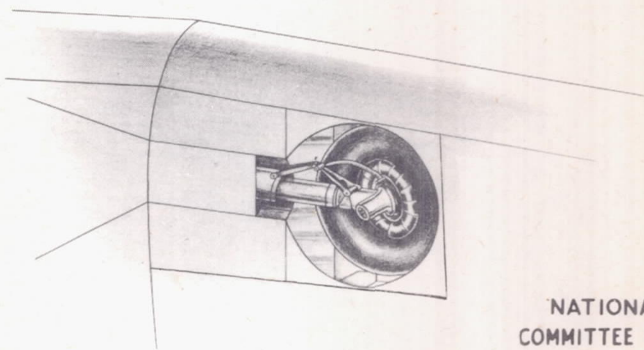


(a) Completely sealed.



ΔC_D, 0.0007
ΔV, 3 mph

(b) Partly sealed wheel wells.



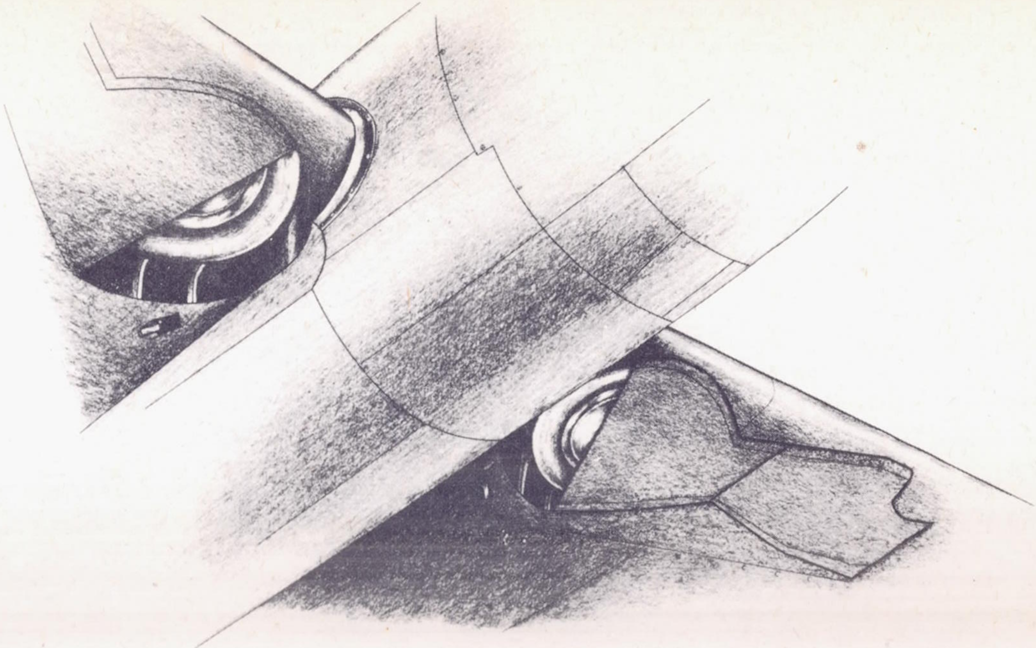
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0014
ΔV, 6 mph

(c) Original wheel well.

Figure 27.- Landing-gear drag on airplane 6.

Completely sealing the open wheel well of airplane 6 decreased the drag coefficient by 0.0014 and partly sealing the wheel well decreased the drag coefficient by 0.0007. The high drag of this installation indicates the importance of sealing open wheel wells. Internal sealing around the wheel well of this airplane and of airplanes 8 and 10 should considerably reduce the drag due to air leakage.

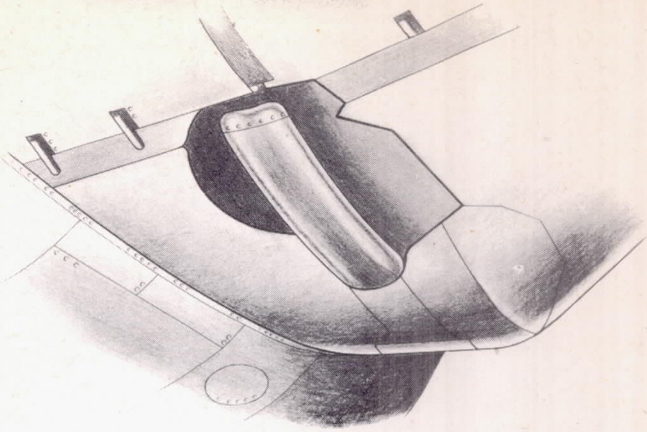


NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0005
ΔV, 3 mph

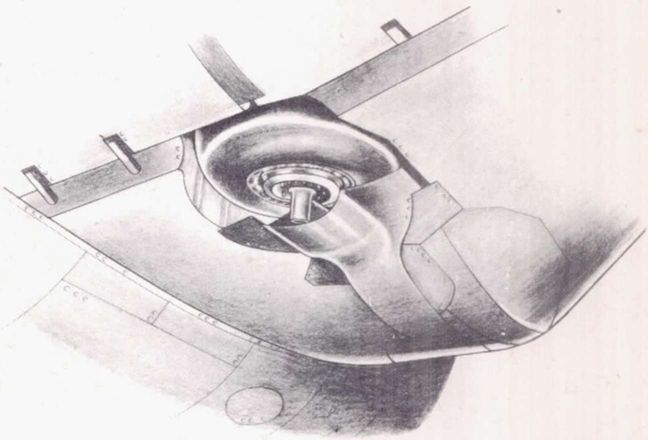
Figure 28.- Landing-gear drag on airplane 8.

The partly open wheel wells on airplane 8 accounted for a drag-coefficient increment of 0.0005. This increment was measured when cover plates were removed from the exposed section of the wheel wells.



ΔC_D, 0.0009
ΔV, 4 mph

(a) Original full-length fairing.



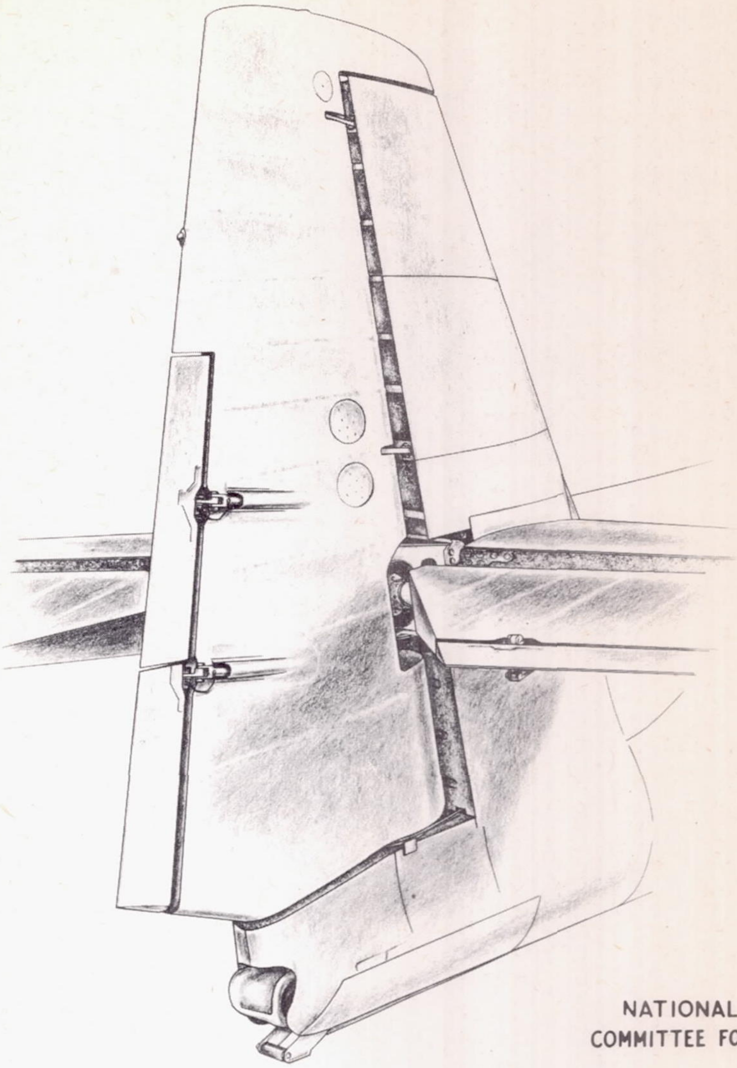
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0012
ΔV, 5 mph

(b) Short-length fairing.

Figure 29.- Landing-gear drag on airplane 10.

Removal of seals from the edges of the original full-length fairing over the retracted landing gear on airplane 10 increased the drag coefficient by 0.0009, thereby indicating that air was leaking through the $\frac{1}{8}$-inch cracks at these points. The short-length fairing, adopted for the production airplane, increased the drag coefficient 0.0012 over that measured for the completely sealed fairing. This drag is due both to air leakage and the air-flow disturbance of the exposed parts. These results show the importance not only of installing a fairing over the wheel but also of completely sealing the wheel-well opening.



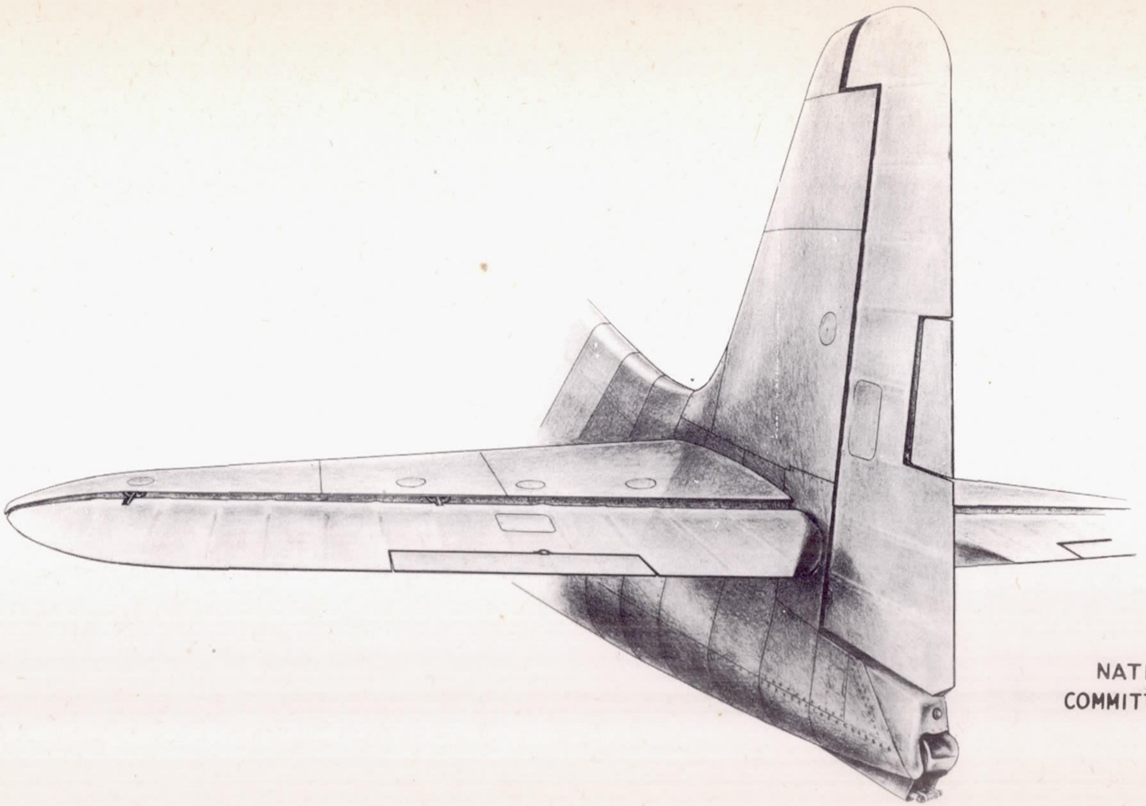
ΔC_D, 0.0009
ΔV, 5 mph

(a) Airplane 6.

Figure 30.- Tail-gap drag.

An increase in drag was measured when the tape seals and metal fairings were removed from the gaps on the horizontal and vertical tail surfaces of these airplanes. In order to reduce the drag due to these gaps, the lightening holes in the spars of the fixed part of the tail should be sealed, the gaps between the fixed and movable surfaces should be made as small as possible, and the fuselage should be sealed off at a rear bulkhead.

[redacted]



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0005
ΔV, 3 mph

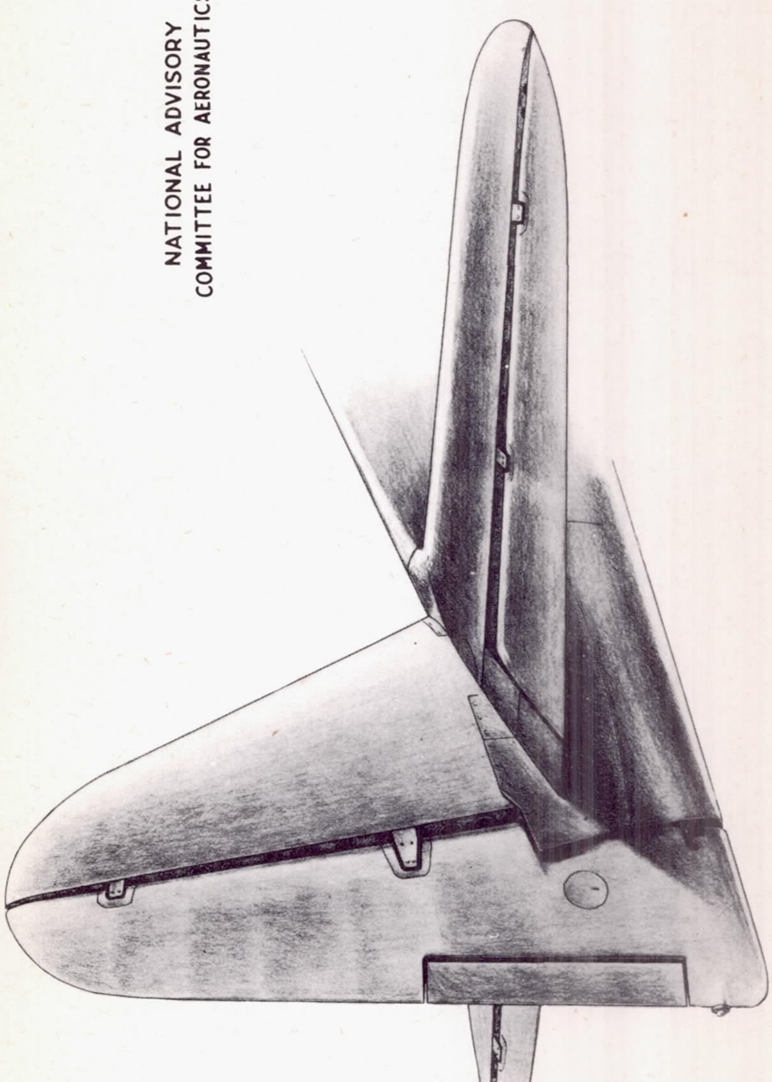
(b) Airplane 10.

Figure 30.- Continued.

[redacted]

CONFIDENTIAL

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



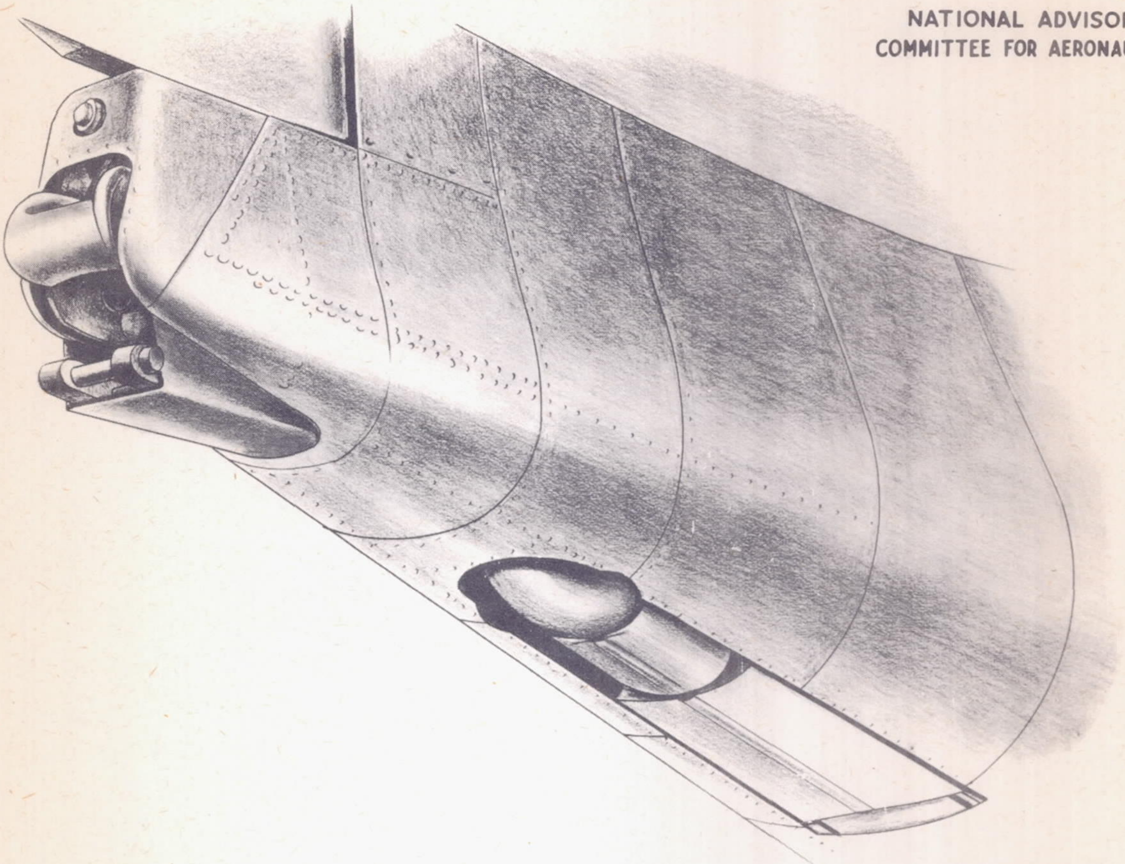
ΔC_D, 0.0007
ΔV, 4 mph

(c) Airplane 11.

Figure 30.- Concluded.

CONFIDENTIAL

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

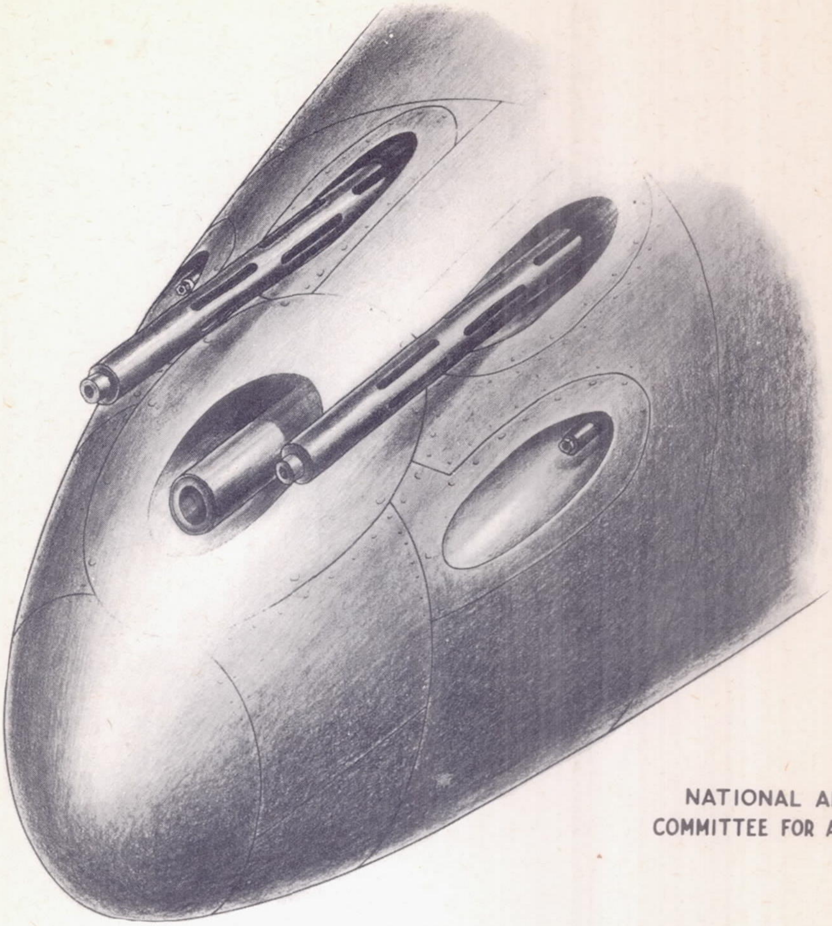


ΔC_D, 0.0005

ΔV, 3 mph

Figure 31.- Drag of tail wheel and arresting hook on airplane 10.

Removing seals and fairings from the openings at the tail wheel and arresting hook of airplane 10 increased the drag coefficient by 0.0005. This increment is largely due to leakage through these openings. The drag of these items can be reduced by external fairing and sealing or by internal sealing of the bulkhead in front of the tail-wheel well.

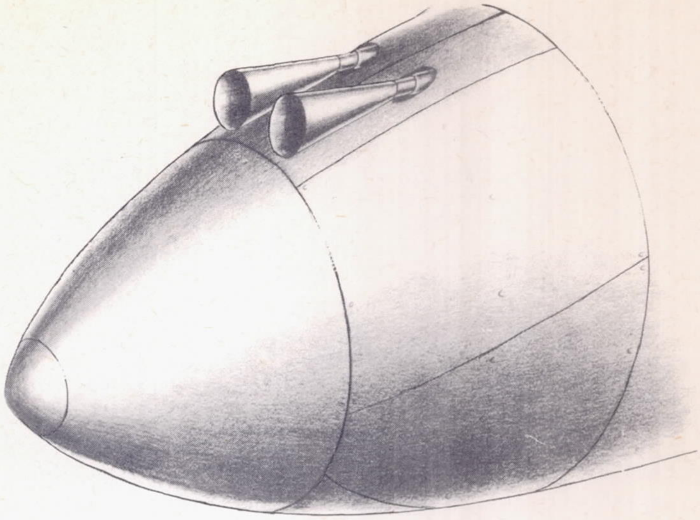


ΔC_D, 0.0008

ΔV, 5 mph

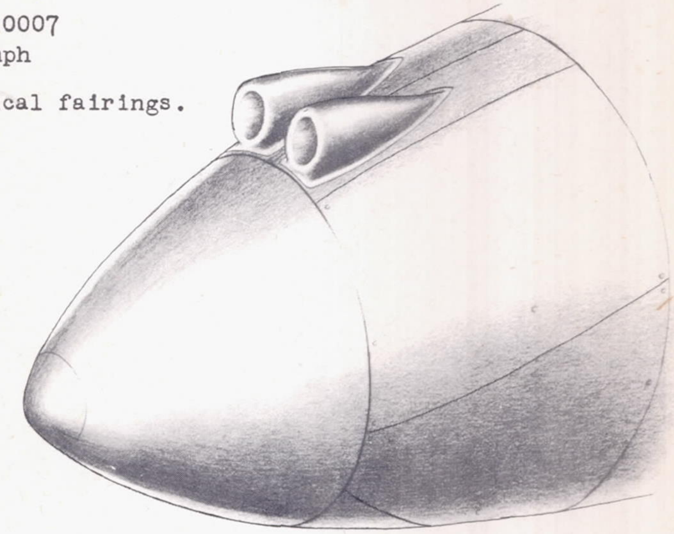
Figure 32.- Armament drag on airplane 4.

The drag-coefficient increment due to the installation of one 37-millimeter cannon, two .50-caliber machine guns, and two .30-caliber machine guns in the nose of this airplane was 0.0008. This drag was measured as the difference between the smooth nose and the nose with guns installed. Internal sealing by means of close-fitting plates around the guns at the bulkhead through which the guns project should eliminate a large part of this drag.



ΔC_D, 0.0007
ΔV, 5 mph

(a) Original conical fairings.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

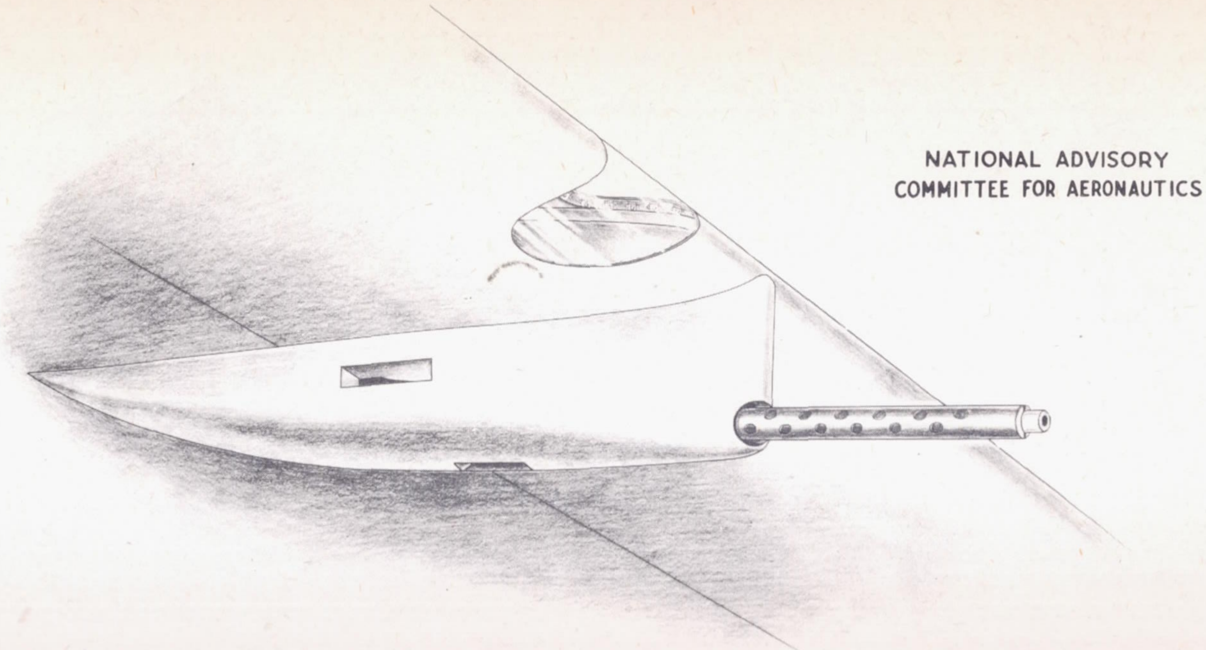
ΔC_D, 0.0003
ΔV, 2 mph

(b) Modified installation.

Figure 33.- Gun blast tubes on airplane 11.

The nose guns on airplane 11 were equipped with conical fairings to prevent the flashes of gun fire from blinding the pilot. Removing the fairings and sealing the gun ports decreased the drag coefficient by 0.0007. The modified installation that eliminated the sharp edges of the original funnel-type fairings increased the drag coefficient only 0.0003 above that measured for the smooth nose with no guns.

[redacted]

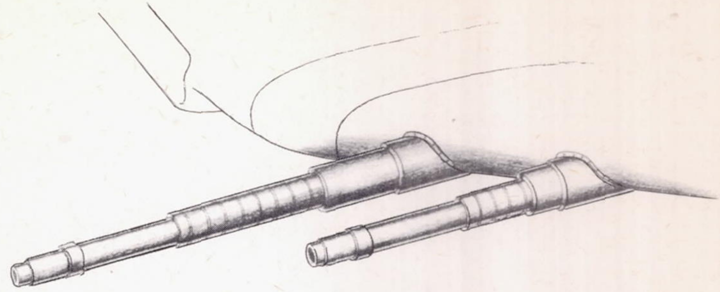


ΔC_D, 0.0010
ΔV, 6 mph

Figure 34.- Armament drag on airplane 11.

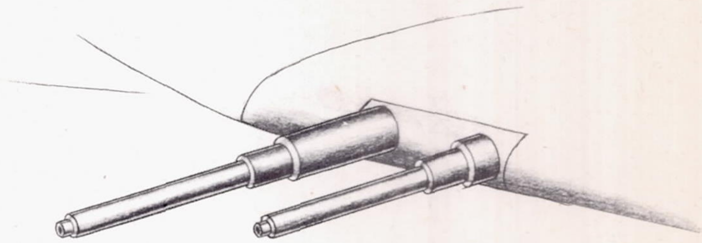
The drag coefficient was increased 0.0010 by installing a .50-caliber underslung wing gun of type shown on each wing. Test results showed that this increment could be reduced to 0.0007 by sealing the gun port in the nose of the fairing. Because of its external location, this type of gun installation usually leads to high drag.

[redacted]



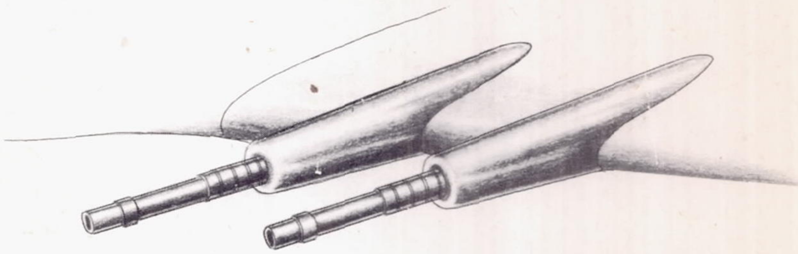
ΔC_D, 0.0002
ΔV, 1 mph

(a) Airplane 9.



ΔC_D, 0.0004
ΔV, 2 mph

(b) Airplane 10.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0005
ΔV, 3 mph

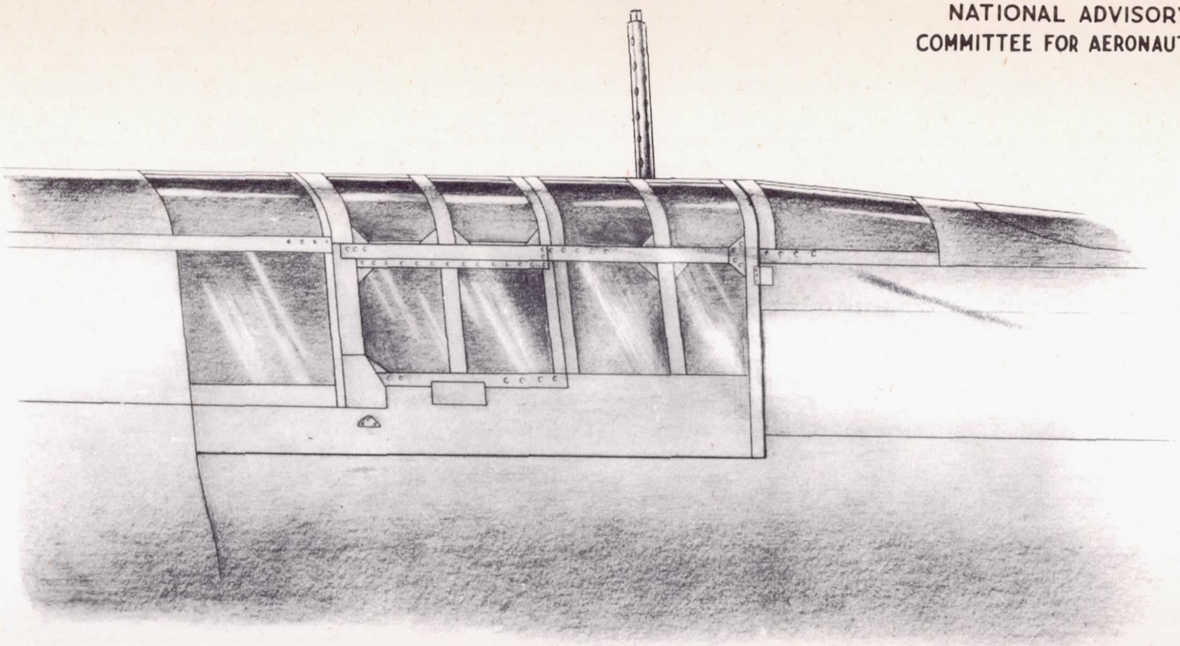
(c) Airplane 12.

Figure 35.- Cannon drag.

The drag increments due to the installation of two dummy 20-millimeter cannons on each wing of airplanes 9, 10, and 12 were low. Service cannon installations that are faired and sealed should give similarly low drag increments.

[redacted]

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

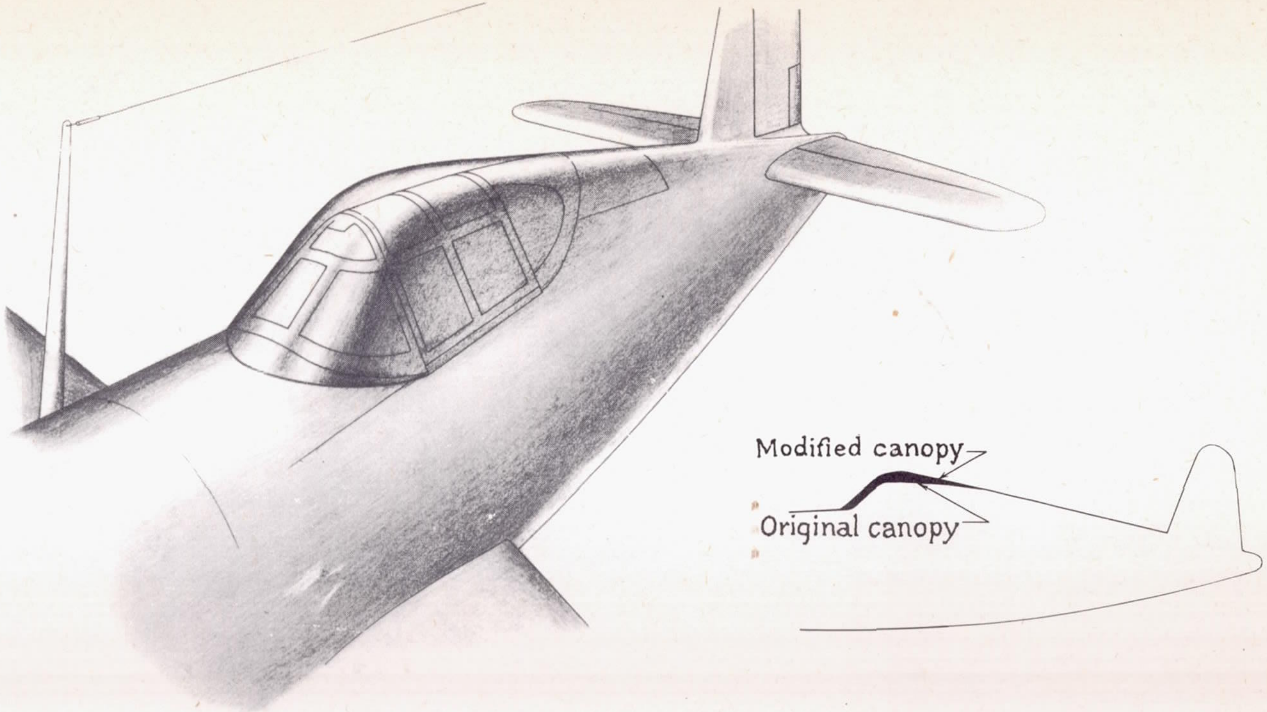


ΔC_D, 0.0007
ΔV, 3 mph

Figure 36.- Armament drag on airplane 8.

This view of the rear canopy of airplane 8 shows that about 1 foot of the barrel of the .50-caliber rear gun is exposed to the air stream. Stowing the gun within the fuselage should eliminate this drag increment.

[redacted]



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

ΔC_D, 0.0004

ΔV, 2 mph

Figure 37.- Canopy installation on airplane 9.

A well-rounded canopy was installed to eliminate the sharp peak of the original canopy of airplane 9. Although the modified canopy was larger in order to afford the pilot greater visibility, the canopy drag coefficient was decreased by 0.0004.

CONFIDENTIAL

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

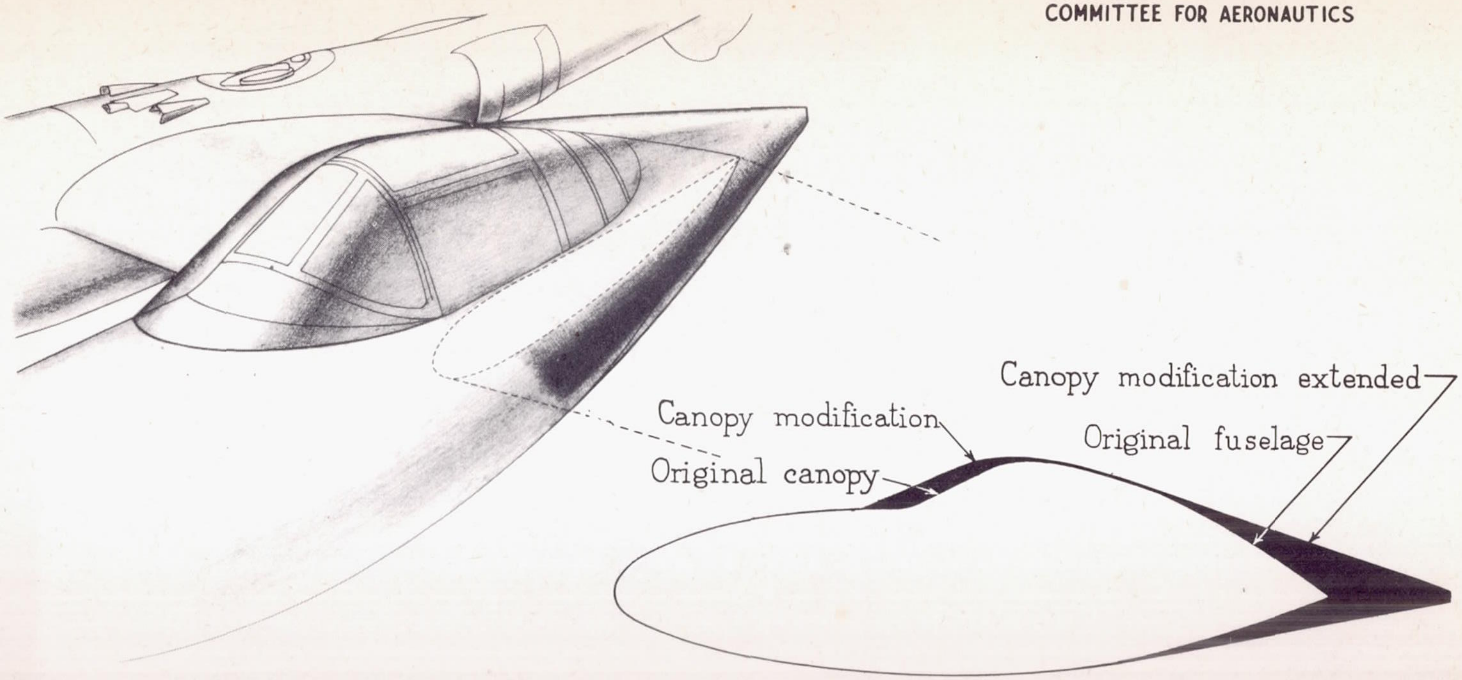
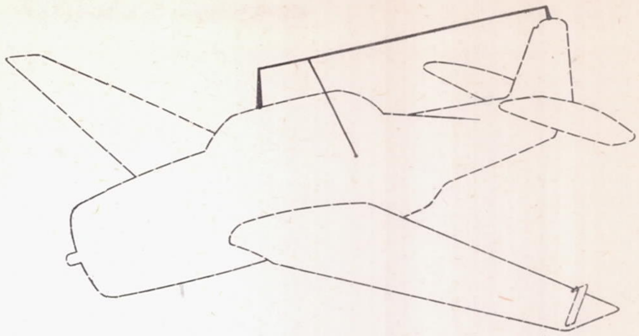


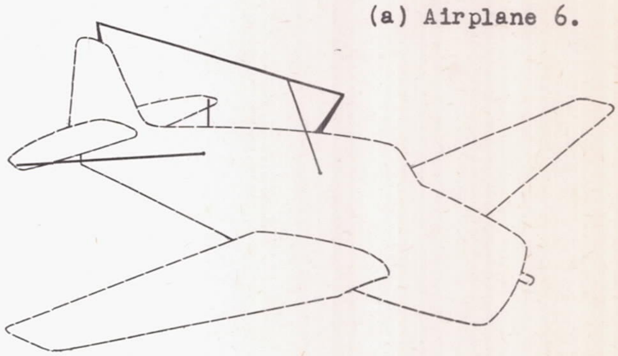
Figure 38.- Canopy modification on airplane 4.

The canopy modification for airplane 4, which included a 3-foot extension of the afterbody, was designed to reduce the high negative pressures over the canopy peak and to prevent flow separation at the rear of the canopy. The critical speed of the canopy was increased by 44 miles per hour as a result of this modification. Drag results are unavailable for these configurations.



ΔC_D, 0.0004
ΔV, 2 mph

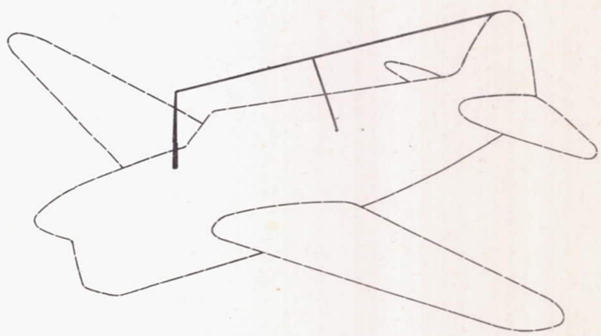
(a) Airplane 6.



ΔC_D, 0.0003
ΔV, 1.5 mph

(b) Airplane 10.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

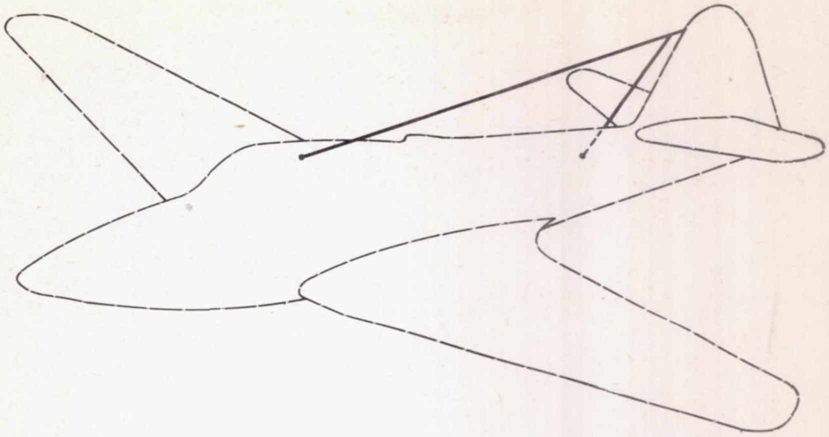


ΔC_D, 0.0004
ΔV, 2 mph

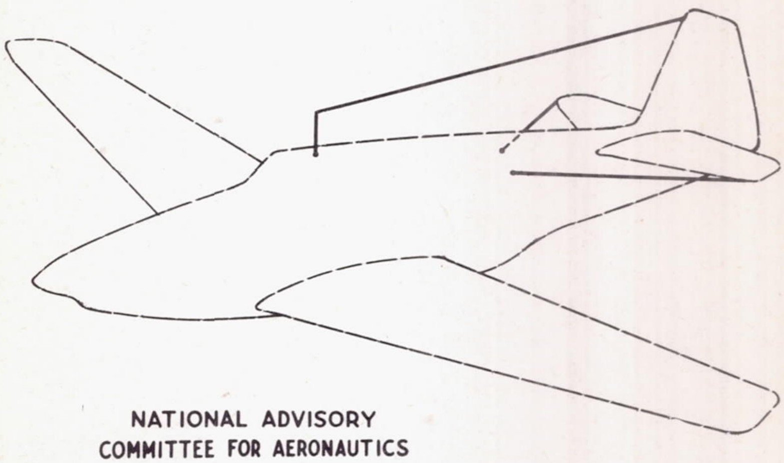
(c) Airplane 2.

Figure 39.- Radio-antenna drag on airplanes 6, 10, and 2.

The drag-coefficient increments were measured as the difference between the drag with radio antennas installed and removed. The drag due to each of these installations is excessive and is due mainly to the thick antenna masts. Low-drag radio-antenna installations are shown in figure 40.



(a) Airplane 11.



(b) Airplane 12.

Figure 40.- Radio-antenna drag on airplanes 11 and 12.

No increase in drag was measured when these radio antennas were installed on the airplanes.