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DRAG OF SEVERAL GUNNER'S ENCLOSURES AT HIGH SPEEDS

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SUMMARY

The drag of several types of gunner's turrets, windshields, blisters, and other protuberances, including projecting guns, was investigated at speeds from 75 to 440 miles per hour in the NACA 8-foot high-speed wind tunnel. The various gunner's enclosures were represented by 1/10 and 1/7 full-size models on a midwing-fuselage combination representative of bomber types.

Most of the usual types of retractable turrets are very poor aerodynamically; they caused drag increments, dependent upon the size of the turret relative to the fuselage and upon the speed, up to twice the drag of the fuselage alone. A large streamline blister sufficient to enclose completely one type of rotating cylindrical turret caused a drag increment of approximately one-half that of the turret and at the same time provided space adequate for two gunners rather than for one gunner.

A large portion of the drag increments for some types of turret appeared to be due to adverse effects on the fuselage flow caused by the turret rather than by the direct drag of the turret.

INTRODUCTION

The drag of standard types of armament installation has become vitally important with increased speeds of the airplane. These installations appear to have been generally determined by considerations other than aerodynamic; basic aerodynamic considerations indicate that some types of armament installation may have marked detrimental effects on the drag of the airplane.

Retractable-armament installations that may be satisfactory in ordinary flight when retracted are used, but their use reduces speed during an important phase of the flight operation; namely, when the airplane is being attacked and speed may be important. Thus, it is evident that improved types of armament installation employing aerodynamic principles that reduce drag effects are especially desirable.

Prior to the present investigation some miscellaneous tests were made in connection with specific designs; these tests were made generally at a very low Reynolds number and, in all cases, the speeds were so low that important compressibility effects were not determined. Because of the lack of data, the aerodynamic effects of various installations on the performance of the airplane could not be determined and their relative merits could not be evaluated.

The purposes of the present investigation are to provide necessary information to determine the aerodynamic effects of various armament installations on airplane performance and to indicate possibilities of improvement.

The types of armament installation investigated include conventional retractable cylindrical turrets, some modifications of these turrets, fixed-dome turrets, tail turrets, side-protruding windshields, various types of blister, and retractable rear-firing platforms. In general, for each type of enclosure at least two sizes were tested in order to represent installations for two sizes of bomber. Models of machine guns of 30 and 50 caliber and 37-mm cannons were also tested on the various installations and on the fuselage alone. All installations were investigated in various positions on the fuselage.

These tests were conducted in the NACA 8-foot high-speed wind tunnel for speeds from 75 to 440 miles per hour. The models of the gunner's enclosure, 1/10 to 1/7 full-scale, were mounted on a midwing-fuselage combination representative of good aerodynamic design.

APPARATUS AND METHOD

The NACA 8-foot high-speed tunnel in which the investigation was conducted is a single-return, closed-throat, circular-section wind tunnel. The air speed is continuously controllable from approximately 75 to more than 500 miles per hour.

The wing-fuselage combination used was a 1/7-scale model of a hypothetical bomber design furnished by the U.S. Army Air Corps, for use in connection with another investigation. A drawing of the model is given in figure 1.

The wing employed in the tests spanned the test section of the tunnel (fig. 2). The wing tips are not represented because the wing extended through openings in the tunnel wall in order to permit the mounting on the balance ring in the standard manner. The wing had a root section of the NACA 0017-34 profile with a chord of 24.7 inches and a projected tip section of the NACA 0009-34 profile with a chord of 8.2 inches. The taper ratio of the wing was 3:1. The wing area within the tunnel air stream was actually 11½ square feet as compared with a wing area of 12¼ square feet for the complete model to the same scale. The angle of wing setting was 2°.

The wing-fuselage combination, which was constructed of wood, was maintained aerodynamically smooth throughout the tests. Landing gears, tail wheel, and horizontal tail surfaces were not represented. The fuselage was 7 feet long and was mounted as a midwing type.

The gunner's enclosures consisted of several types; namely, turrets, blisters, side-protruding windshields, retractable rear-firing platforms, and protruding prone-firing tubs. Some modifications of the models were also investigated. These models were made to 1/7 and 1/10 scales, which are representative of installations on 49-foot and 70-foot fuselages, respectively. A photograph of the gunner's enclosures tested is given in figure 3. Detailed measurements are given in figure 4 for all the models except the tail turrets shown in figure 1. Designations and descriptions of the models are given in table I. All models were located on the fuselage to correspond with certain full-scale installations and were then moved into different positions for comparison. These locations are shown on the figures that present the drag data. (See figs. 6 to 15.)

The Mach number range for most of the tests extended from 0.15 to 0.58. (See fig. 5.) The corresponding average Reynolds number range based on the mean aerodynamic chord of the complete model (17.7 in.) was 1,000,000 to 4,900,000.

The angle of attack α_F is referred to the fuselage reference line. When α_F is 0°, the root section of the wing is at an angle of attack of 2°. All tests were run with $\alpha_F = 0^\circ$.

All the results presented were obtained with the boundary-layer transition point fixed at its approximate full-scale location by means of a 1/4-inch-wide strip of no. 60 carborundum grains shellacked to the model surfaces. Transition was fixed on both surfaces of the wing along the entire span at 10 percent of the chord. On the fuselage, transition was fixed at 10 percent of the fuselage length. The transition strip itself had a negligible drag.

RESULTS

The results are presented as incremental drag coefficients ΔC_D plotted against Mach number M. For a given type of installation, the drag increment due to the enclosure relative to the airplane proper will vary with the size of the airplane. The increment will be smaller the larger the airplane because the size of the enclosure is fixed by space requirements for the gun installation. Comparison of the enclosures on the basis of drag coefficients determined by using a characteristic area of the enclosure will therefore fail to indicate the over-all drag effects relative to the drag of the airplane proper. In order to indicate the magnitude of the over-all drag effects, the area chosen for determining the drag coefficients is the fuselage cross-sectional area. The incremental drag coefficients are defined as follows:

For the enclosures,

$$\Delta C_D = \frac{\text{Drag of complete model (wing, fuselage, and gunner's enclosure) - drag of wing and fuselage}}{\text{Dynamic pressure} \times \text{fuselage cross-sectional area}}$$

For the fuselage,

$$\Delta C_{D_F} = \frac{\text{Drag of wing-fuselage combination - drag of wing}}{\text{Dynamic pressure} \times \text{fuselage cross-sectional area}}$$

The incremental drag coefficient of the fuselage alone is also presented in figure 6 for comparison.

Thus, the drag coefficients include the interference drag as well as the direct drag.

The combined drag coefficient of the gunner's enclosure and the fuselage may be determined by adding their respective drag coefficients. The Reynolds numbers R_{av} (fig. 5) are the averages of the actual Reynolds numbers R for the various test runs. None of the Reynolds numbers departs from these averages enough to affect the results appreciably.

A general comparison of the most important gunner's enclosures is shown in figure 6. Figures 7 and 8 show the variation of the incremental drag coefficient with the turret location on the fuselage. The effects on the drag of similar enclosures that differ in size, some with modifications, and others with changes in location, or both, are shown grouped together in figures 9 and 10. Figures 11 to 15 present the effects of protruding guns on the various gunner's enclosures and on the fuselage alone.

DISCUSSION

Figure 6 shows the drag results for several types of gunner's enclosures located at 40 to 45 percent of the fuselage length. As would be expected from the general design, blisters BA and BB gave the lowest drag, which was approximately 7 percent of the fuselage drag. It is readily seen that all other types of installation were generally poor aerodynamically; some drag values were as high as 275 percent of the fuselage drag at 350 miles per hour.

Retractable enclosures.- Turrets TA and TB (fig. 6), which have top surfaces curved to fit the fuselage contour, are geometrically similar but differ in size. Turret TA represents a 1/10-scale model and turret TB a 1/7-scale model. The drag variations with Mach number of both models were similar; the drag of both models increased continually above a value for M of 0.35, which corresponds closely to the drag rise of cylinders at their critical speed. At M = 0.25, the drag of turrets TA and TB in percentage of fuselage drag was 81.4 percent and 184 percent, respectively; at $M = 0.45$, the increments were 113 and 275 percent, respectively.

The shape of the turret top had a marked effect on the drag (fig. 6), as is shown by a comparison of the results for turrets TA, TA-1, TA-2, and TA-3. These turrets all projected the same height and differed only in the shape of the top. The flat-top turret TA-1 had a drag approximately 23 percent lower than the drag of the basic turret TA at low speeds; the drag was the same for these turrets, however, when M was greater than 0.35, which indicates the marked effects of compressibility. When the sharp edges were rounded, as on turret TA-2, a decided improvement is made amounting to approximately 40 percent decrease in the drag at $M = 0.30$ and an even greater decrease at higher values of M. Further rounding of the turret, as on turret TA-3, showed a greater improvement at lower speeds but no gain over turret TA-2 at values of M greater than 0.40. The difference at low Reynolds number is probably due to a pronounced separation phenomenon. It will be noted that special provision for enclosing turrets TA-1, TA-2, and TA-3 will be necessary when retracted. In contrast with these retractable types of turret, the permanent dome-type turret TC had approximately one-third of the drag of the fuselage and was superior in this respect to the other cylindrical turrets.

Rotating turret TB 90° had a marked effect. The drag was reduced approximately 30 percent at $M = 0.30$ and more than 40 percent at $M = 0.45$.

The basic cross section of the turrets being cylindrical, it is not surprising that the drag characteristics showed a marked similarity to the drag characteristics for a cylinder. In table II is tabulated a comparison of the drag coefficients C_{D_C} of the various turrets, based on the height above the fuselage and the diameter, with the two-dimensional-cylinder drag coefficient at the same Reynolds number for a Mach number of 0.30. All of the turrets except turret TA-3 had drag coefficients considerably larger than the cylinder drag coefficient, which demonstrates the fact that the turrets cause flow separation for the fuselage and thus effect a large drag increase of the fuselage. It is likely that the flow-separation effects may be decreased by adding a positive lift cap to the turret top, the downflow from which might force the flow to close in back of the turret. This modification was not investigated, however, because it appears to impose uncertain gunnery difficulties.

TABLE II

Comparison of Turret Drag Coefficient C_{D_C} with Two-Dimensional-Cylinder Drag Coefficient for a Mach Number of 0.30

Turret	TA	TA-1	TA-2	TA-3	TB	TB-R	TC	Two-dimensional cylinder
C_{D_C}	0.562	0.515	0.336	0.276	0.641	0.436	0.334	0.248

A further study of table II illustrates the importance of the top shape. Turret TA-2 had about 40 percent less drag than turret TA and turret TA-3 had about 50 percent less drag than turret TA. The difference between the coefficients of turrets TA and TB indicates that larger actual drag effects may result with a smaller airplane, probably because the portion of the drag increment attributable to interference increases as the size of the turret (which must remain essentially constant) increases relative to the airplane size.

The location of the turret is also very important, as is shown in figures 7 and 8. The marked reduction in drag caused by moving the turrets to the rear of the fuselage might be expected in view of the preceding discussion, which shows that a large part of the drag is due to the spoilage of flow on the fuselage in the rear of the turret. Thus, when the turret is located near the tail, the flow along the fuselage is disturbed for a very short distance. The drag values for turrets TA-2 and TA-3 were almost the same as for the cylinder, which indicates a small spoilage of fuselage flow. Again it will be noticed that turrets TA-2 and TA-3 had approximately the same drag in this location, which is an indication that only a small amount of rounding of the top edge is required.

The retractable gunner's windshields GWA and GWB (fig. 6), which have fields of fire to the rear and to the side, were generally poor aerodynamically. The drag and interference for the larger 1/7-scale windshield and the smaller 1/10-scale windshield were approximately 125 percent and 61 percent of the fuselage drag, respectively. This type of windshield is somewhat better aerodynamically than the retractable turret. The locatión in the wake of the wing may account for this difference. These results may differ somewhat for an actual installation because as actually applied, the air can flow in through the rear portion of the windshield. This effect is probably small, however, because a comparison of the drag coefficient based on the frontal area of the windshield with the cylinder drag coefficient indicates a separated region behind the windshield. The drag coefficient based on the frontal area was 0.4 for the smaller gunner's windshield GWA and 0.5 for the larger gunner's windshield GWB, while the cylinder drag coefficient was 0.248. From the investigations of the location of other gunner's enclosures on the fuselage, it is probable that the drag for the windshields will be greater if they are moved farther forward.

The retractable rear-firing gunner's platform (figs. 4 and 10) had a drag lower than the retractable, cylincrical, rotating turrets. The larger size PB, the 1/7-scale model, had about the same drag as the large gunner's windshield, which was 125 percent of the fuselage drag. The smaller platform had approximately one-third of the drag of the fusealge. Figure 10 shows that a rearward movement of the platform caused a decrease in drag and indicates that, as with the cylindrical turrets, a large part of the drag was due to the spoilage of the fuselage flow.

Nonretractable enclosures.- The tail turrets TT-1 and TT-2 described in table I and sketched in the model drawing (fig. 1) gave drag increments of 59 percent of the fuselage drag for the blunt cylindrical end and 38 percent of the fuselage drag for the elliptical end. These large increments indicate flow separation at the tail of the fuselage.

Figure 6 shows that the drag of blisters BA, BB, and BC is less than that of any of the gunner's enclosures listed. The drag increments vary from 5 to 17 percent of the fuselage drag, depending on the size of the blister. These blisters are the most preferable aerodynamically of the gunner's enclosures tested. The location of these blisters, unlike the location of the cylindrical turrets and the rear-firing platforms, does not cause drag decreases by rearward movement; instead, the blisters prove to be good in almost any location, their lowest drag increments being apparent nearest the nose. The data indicate that there is very little spoilage of the fuselage flow by the blisters. It is also interesting to note that blisters BA and BB, when located near the nose, caused no drag increment at high Mach numbers. The spherical-nose blister, differing from blisters BA, BB, BC in design, caused a drag increment of approximately 5 percent of the fuselage drag.

The blister forms showed the best aerodynamic results; they are generally not desired, however, because of poor arrangements for gunners. This difficulty may possibly be overcome by using very large blisters sufficient to streamline the turret. Such a blister would be sufficient to mount more guns and possibly one more gunner.

Blister BC (figs. 4 and 6) was of a size large enough to enclose turret TA; the drag of blister BC, however, was only one-sixth of the worst and one-third of the best of the A-type turrets. The larger blister is clearly better aerodynamically and will likely permit room for additional guns and one extra gunner. A permanent streamline blister causes a slight added drag at all times in contrast with a retractable turret, which adds no drag under normal flight but greatly increases the drag when extended at a most important phase of the flight; namely, when the airplane is attacked and speed may be important. The streamline blister, when properly designed, will likely provide sufficient space to give greater fire power and less drag during combat than the retractable turret.

The tub-type blisters BTA and BTB (figs. 4 and 9) are of sufficient size to contain one or two gunners in a prone position. These blisters are superior to the turret with respect to drag. Blister BTB, which had the same over-all height as turret TB, had drag values less than one-half of turret TB rotated in its best position. If blister BTB is used on the upper side of the fuselage in place of a rotating turret, the drag will be greatly reduced and adequate space will be available for two gunners standing or seated within the fuselage. The drag of blister BTB is about two and one-half to four times that of blister BC. If special arrangements for the gunnery can be made to permit the use of good streamlining of the tub types, the drag in relation to the fire power would be extremely low.

<u>Protruding guns</u>.- The actual drag due to protruding guns cannot be accurately determined from these tests because large scale effects on the direct drag due to the guns may be expected with the guns in any position except

along the flight axis. The guns, generally cylindrical, may be subject to scale effects similar to those found for cylinders. Interference effects, however, are probably well represented.

Figures 11 and 12 show the effects of protruding guns on retractable turrets. As might be expected, the worst condition for the gun existed when it was pointed sidewise. Practically no increase in drag was noticed when the gun pointed to the rear; this result can be expected because the gun was in the wake of the turret and could contribute only skin friction plus a small separation effect at the muzzle. When the gun was vertical or 45° forward, there was a decrease in drag for the combination. This decrease in drag can be attributed to the flow disturbance caused by the gun bringing about a mixture of the relatively high-energy air of the undisturbed flow well away from the turret with low-energy air in the separated region around the turret, thus establishing a sort of scouring action that reduced the size of the separate wake. The 30-caliber and the 50-caliber guns showed the same effects generally, differing only in degree.

When the turret top was rounded, like turrets TA-2 and TA-3, the addition of guns in the vertical or the 45° forward positions was no longer beneficial to the flow over the top as was the case for turrets TA and TA-1; in fact, the addition caused decided increases in the drag. It is evident that the flow over turrets TA-2 and TA-3 had a smaller separation region; when the guns were added, this separation region was increased and further spoilage of the air flow over the fuselage resulted.

Figure 13 gives the effect of protruding guns on blisters and, as is to be expected, there was an appreciable drag increase when the gun protruded vertically or forward.

Adding a gun to the tub blister (fig. 13) caused a decrease in the drag at the lower Mach numbers and an increase in drag at the higher Mach numbers. This effect is exactly opposite to the effect produced by adding guns to turrets TA and TA-1 and is probably due to a peculiar characteristic of the tub-type blister. At low speeds and low Reynolds numbers the drag of the blister alone is high but with increasing speeds or increasing Reynolds numbers a critical value is reached at which the drag drops sharply. Phenomena similar to those occurring at the critical Reynolds number for a sphere or a cylinder probably occur. The addition of the gun, like the addition of a protuberance to a sphere or a cylinder, causes a decrease in the critical Reynolds number. This characteristic of the tub-type turret is an important consideration regarding its application. The Reynolds number for an actual installation is well above the critical value indicated by the drag curves of figures 9 and 13. It should be expected that the high drag values shown by the low-speed results of this investigation could not be obtained and, therefore, the drag coefficients actually encountered would be more nearly like the values given by the high speed results.

The effect of protruding guns on the gunner's windshield is shown in figure 14. There is a small change in drag when the guns protrude to the side but no noticeable change when the guns point to the rear, which is to be expected because the guns are then in the wake of the windshields.

The effect of guns projecting from the fuselage surface is presented in figure 15. The drag increments vary from 5 to 15 percent of the fuselage drag, depending on the size and the location of the gun.

CONCLUDING REMARKS

The form of presentation has been chosen to illustrate the drag effects in terms of the fuselage drag. The actual coefficients shown differ with the size of the airplane. It will be noted that the turrets remain essentially the same size with variations in the airplane size because the space required for the gunner and his equipment remains constant and therefore the drag effects tend to be larger with smaller airplanes and smaller with larger airplanes.

It appears desirable to consider seriously the use of large blisters rather than retractable cylindrical turrets. Ultimately, on large airplanes one or two well-streamlined enclosures to permit excellent vision and with remote control for retractable guns or enclosed guns mounted to swivel about the muzzle seem probable.

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

TABLE I

GUNNER'S ENCLOSURES TESTED

[Fuselage cross-sectional area, 0.612 sq. ft]

Type	Designation	Basic frontal area of model (sq ft)	Description
Retractable cylindrical turrets.	TA	0.0525	Conventional top curved to fuselage contour. Represents 37-inch-diameter turret on 70-foot fuselage.
Do - - - -	TA-1	.0562	Same as TA, except flat top.
Do - - - -	TA-2	.0533	Same as TA-1, except edge rounded.
Do - - - -	TA-3	.0463	Same as TA, except spherical top.
Do - - - -	TB	.114	Same as TA, except for size. Represents 37-inch-diameter turret on 49-foot fuselage.
Do - - - -	TB-R	.126	Same as TB, except rotated 90°.
Fixed-dome turret.	TC	0.0402	Similar to TA-2, except larger diameter, smaller height, and faired into fuselage.
Tail turret.	TT-1	-------	Represents fuselage lines altered to represent 42-inch-high, 35-inch-wide turret in tail; end is a vertical cylinder.
Do - - - -	TT-2	-------	Same as TT-1 except end faired elliptically.
Tear-drop blister.	BA	0.0229	Cylindrical cross section.
Do - - - -	BB	.0298	Larger than BA; elliptical cross section.
Do - - - -	BC	.0556	Larger than BB; elliptical cross section.
Spherical-nose blister.	BS	0.0147	Nose-gun housing. Represents 26-inch-diameter blister on 70-foot fuselage.
Protruding prone-firing tub blister.	BTA	0.0316	Represents 15-inch-deep, 100-inch-long, and 30-inch-wide tub type on 70-foot fuselage.
Do - - - -	BTB	.0768	Same as BTA, but larger. 30-inch-deep, 120-inch-long, 36-inch-wide.
Retractable rear-firing platform.	PA	0.0312	Represents platform 70 inches long, with rear opening 30 inches wide, and 15 inches deep on a 70-foot fuselage.
Do - - - -	PB	.0750	Same as PA, except larger.
Side-protruding windshield.	GWA	0.0433	Represents gun position for 70-foot fuselage.
Do - - - -	GWB	.0877	Same as GWA, except larger. Simulates gun position for 49-foot fuselage.

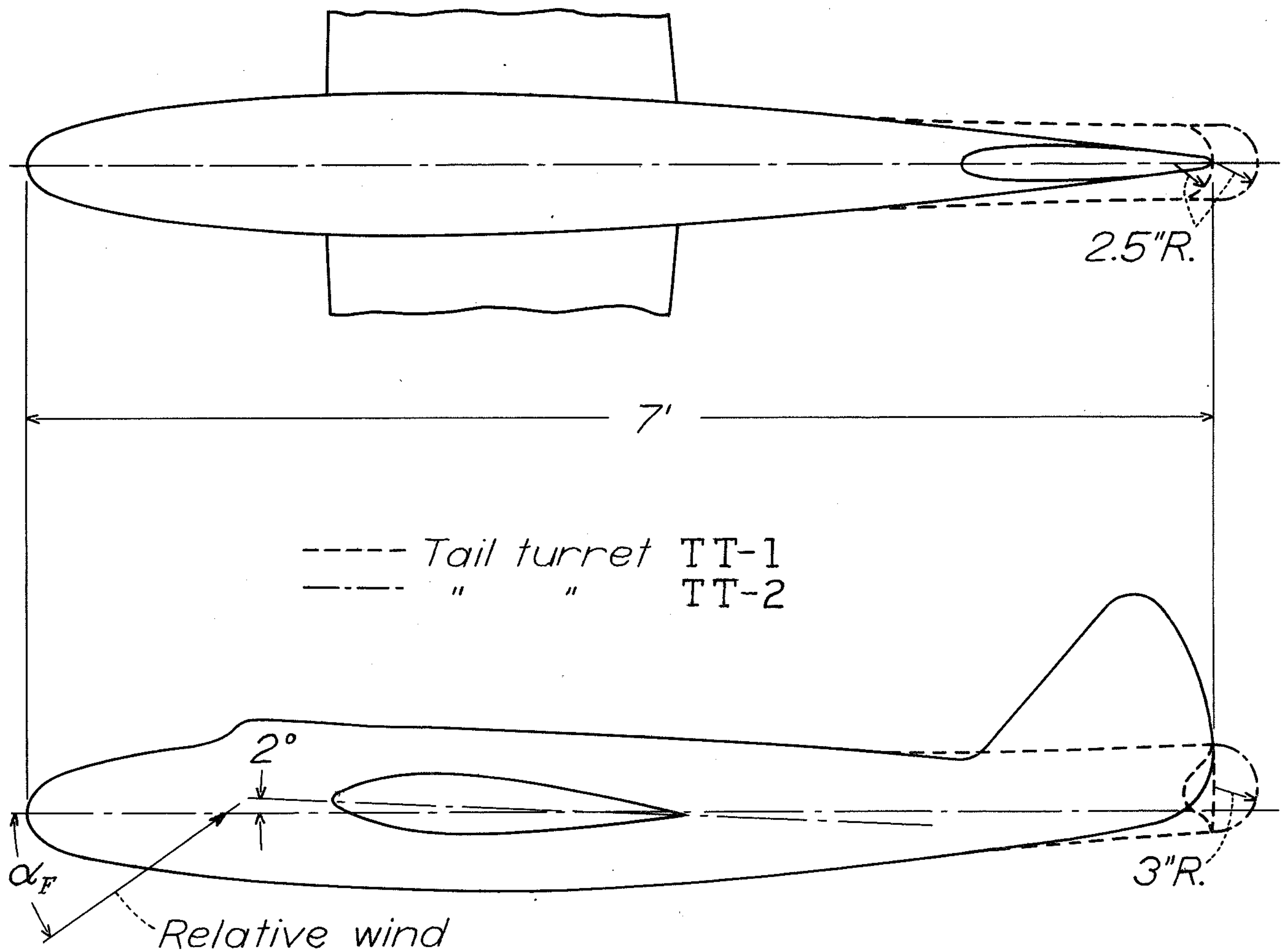

Figure 1.- Model showing tail-turret type of installation.

Max X-AREA = .612 □'

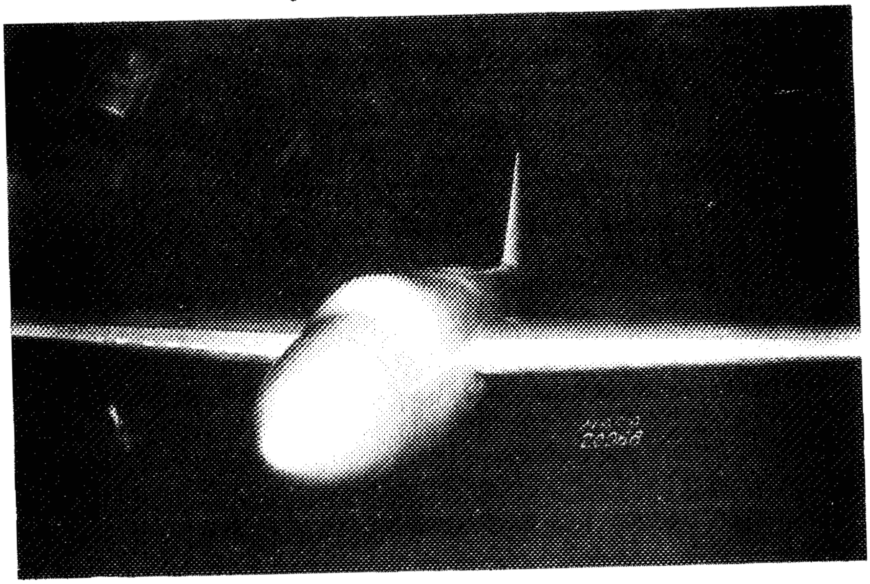

Figure 2.- Wing-fuselage combination as mounted in the 8-foot high-speed tunnel.

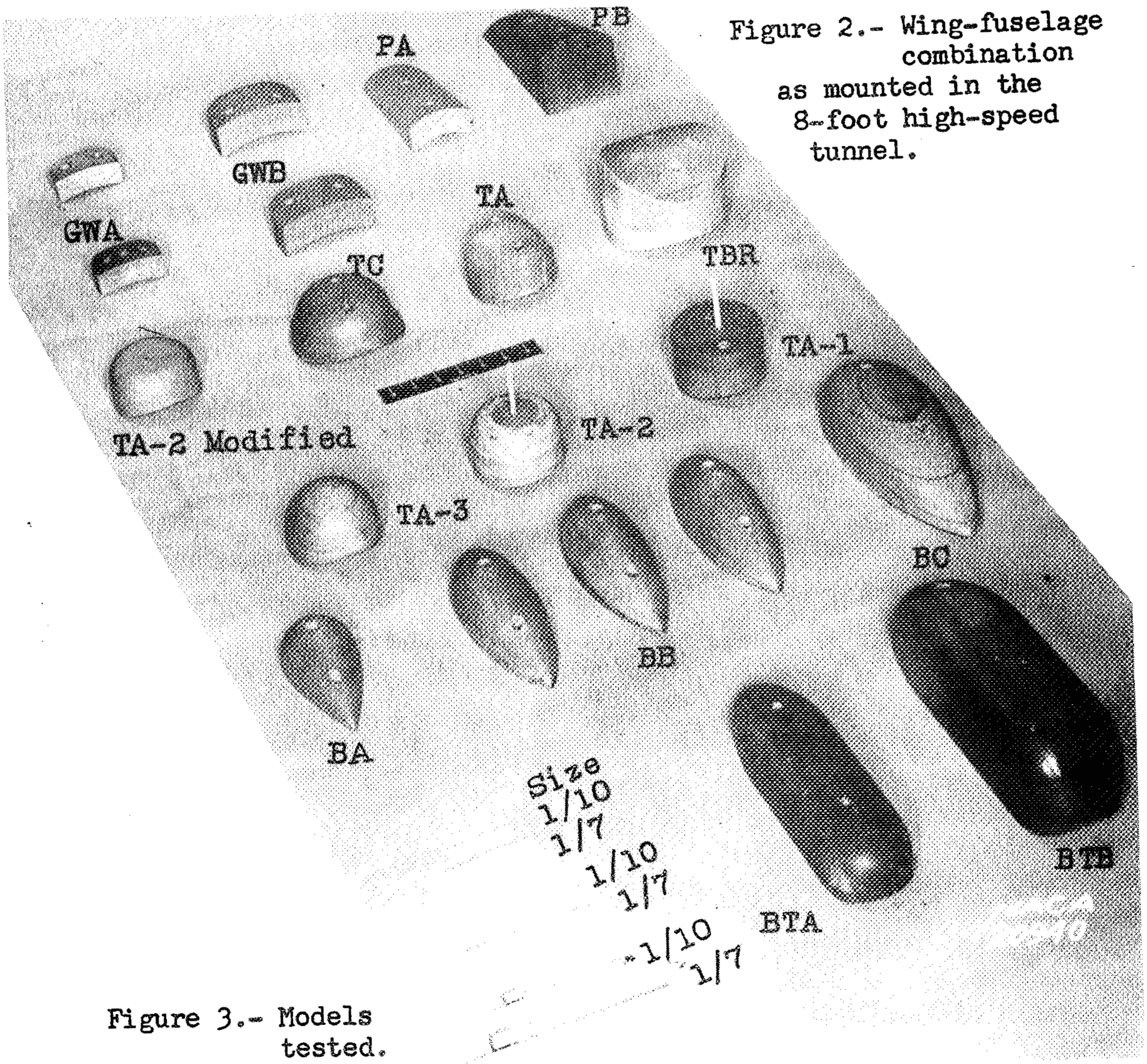

Figure 3.- Models tested.

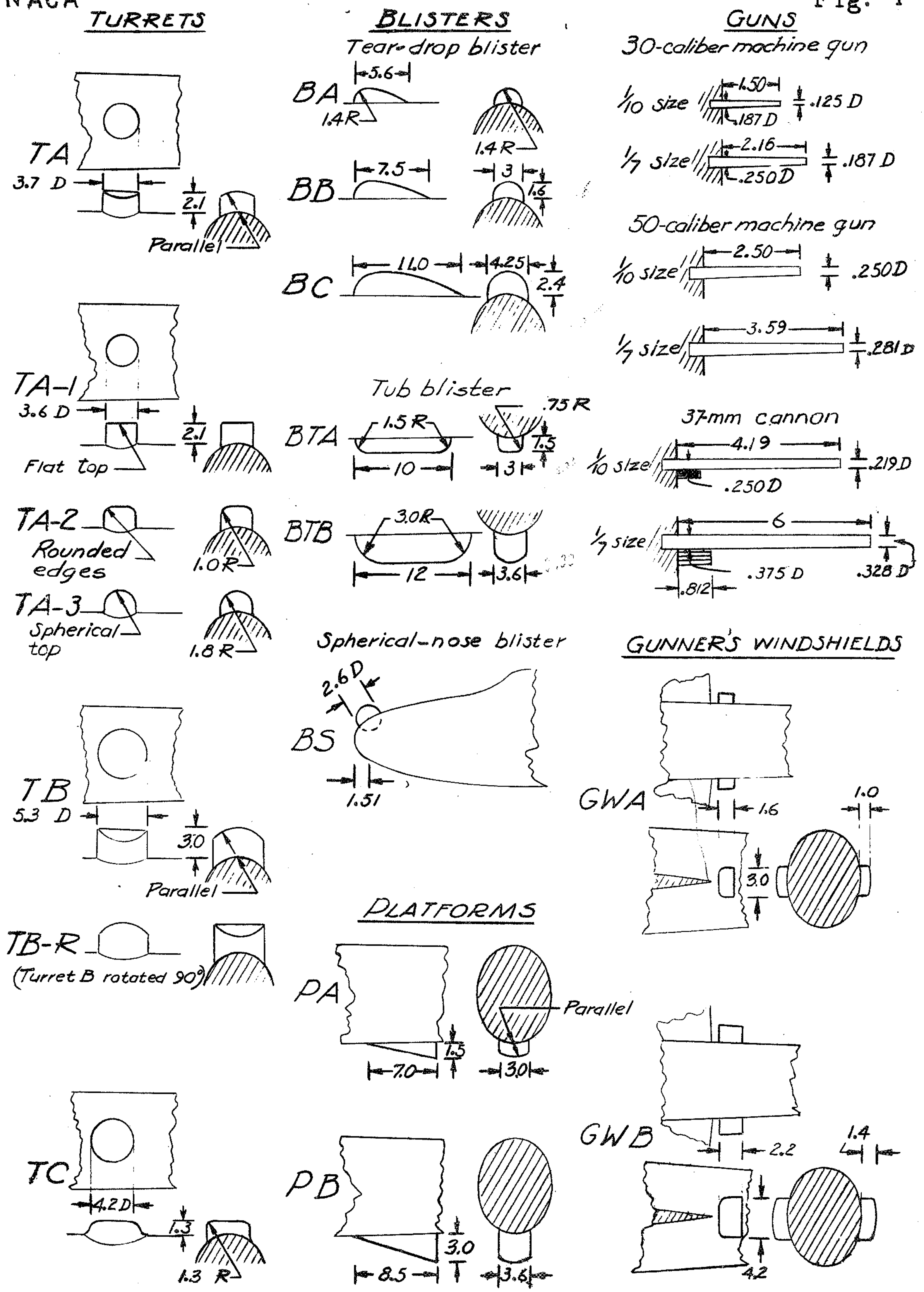

Figure 4 - Detail sketches of the models tested. All dimensions are in inches.

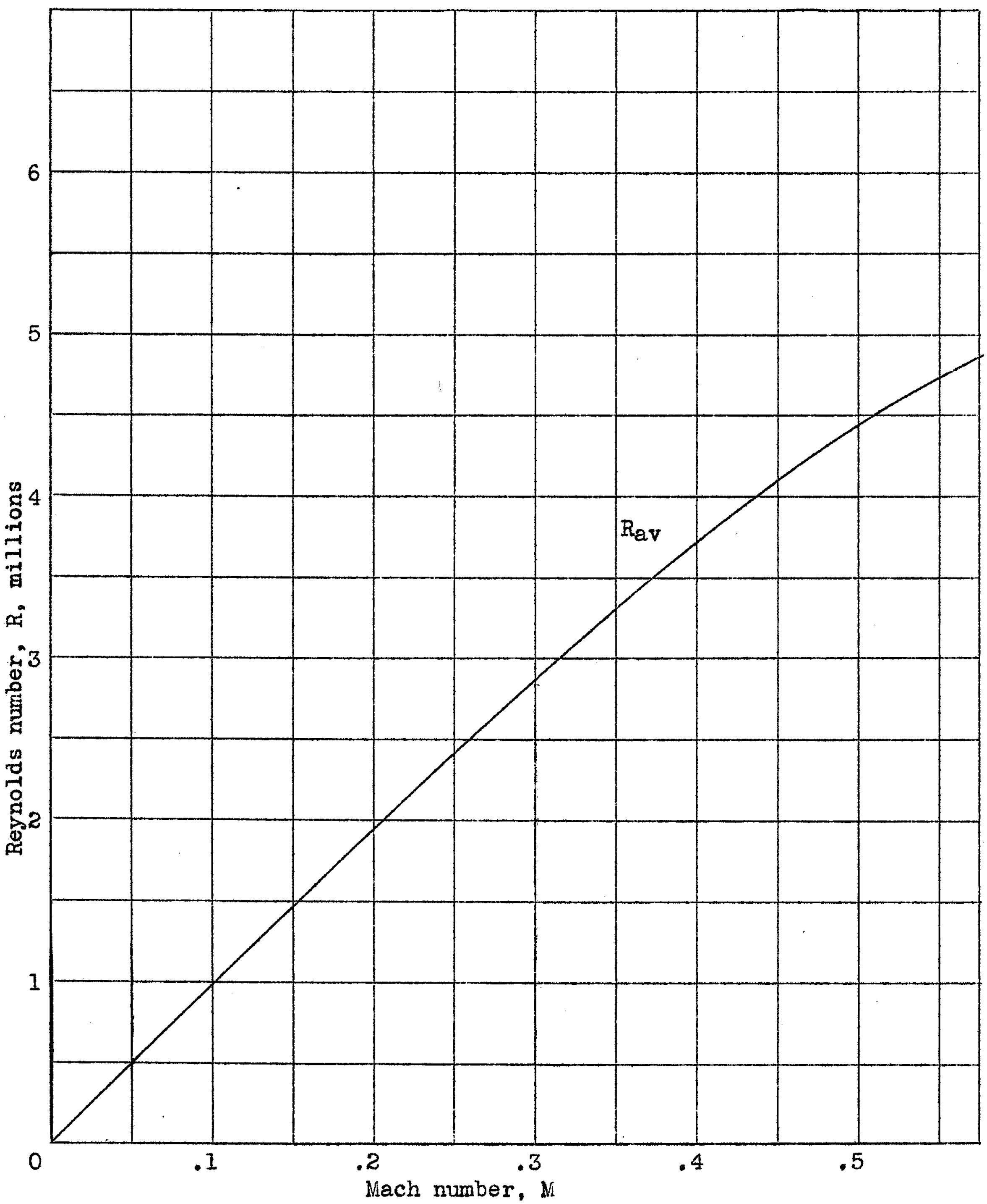

Figure 5.- Variation of test Reynolds number with Mach number.

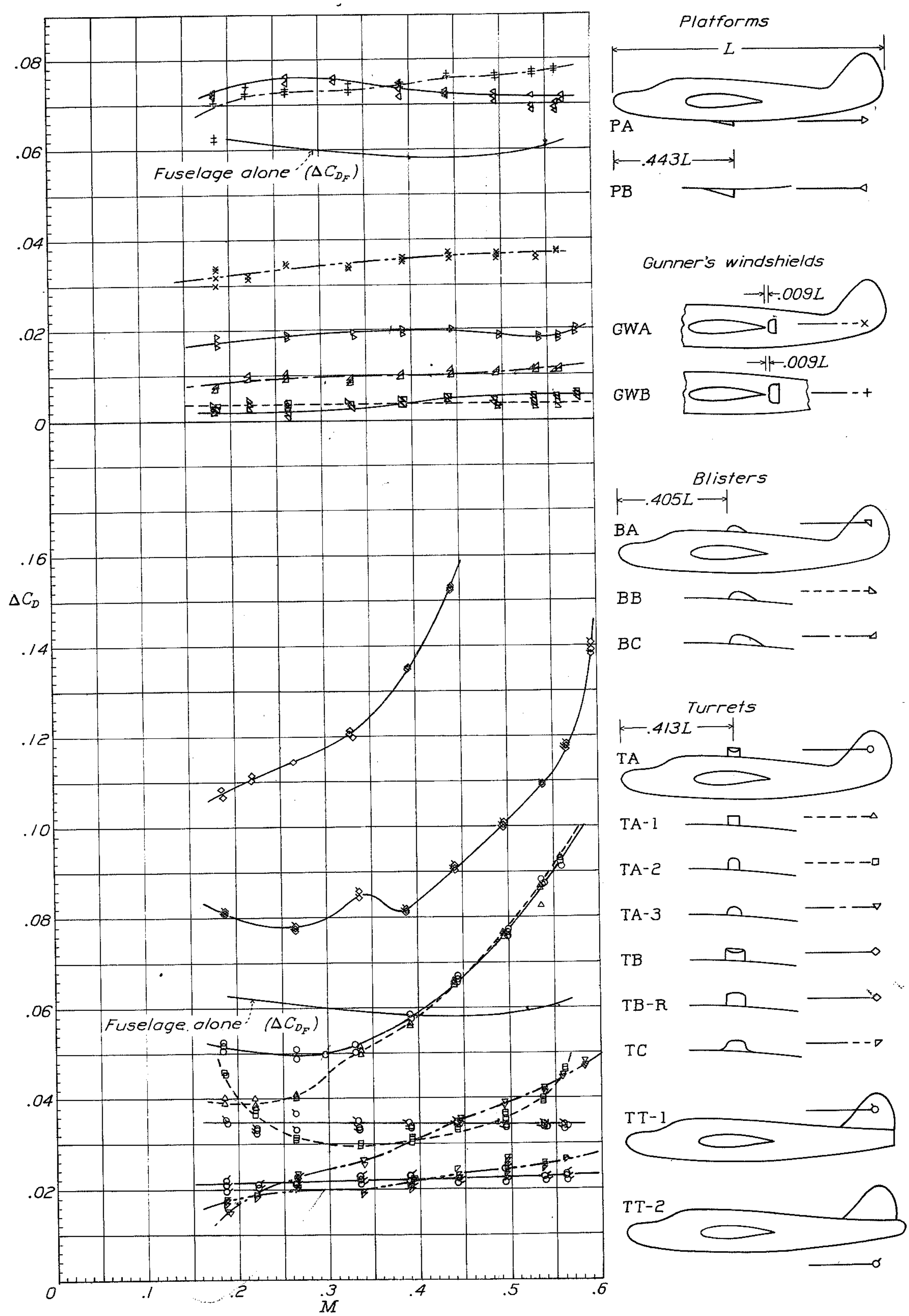

Figure 6.- Variation of incremental drag coefficient with Mach number for various gunner's enclosures.

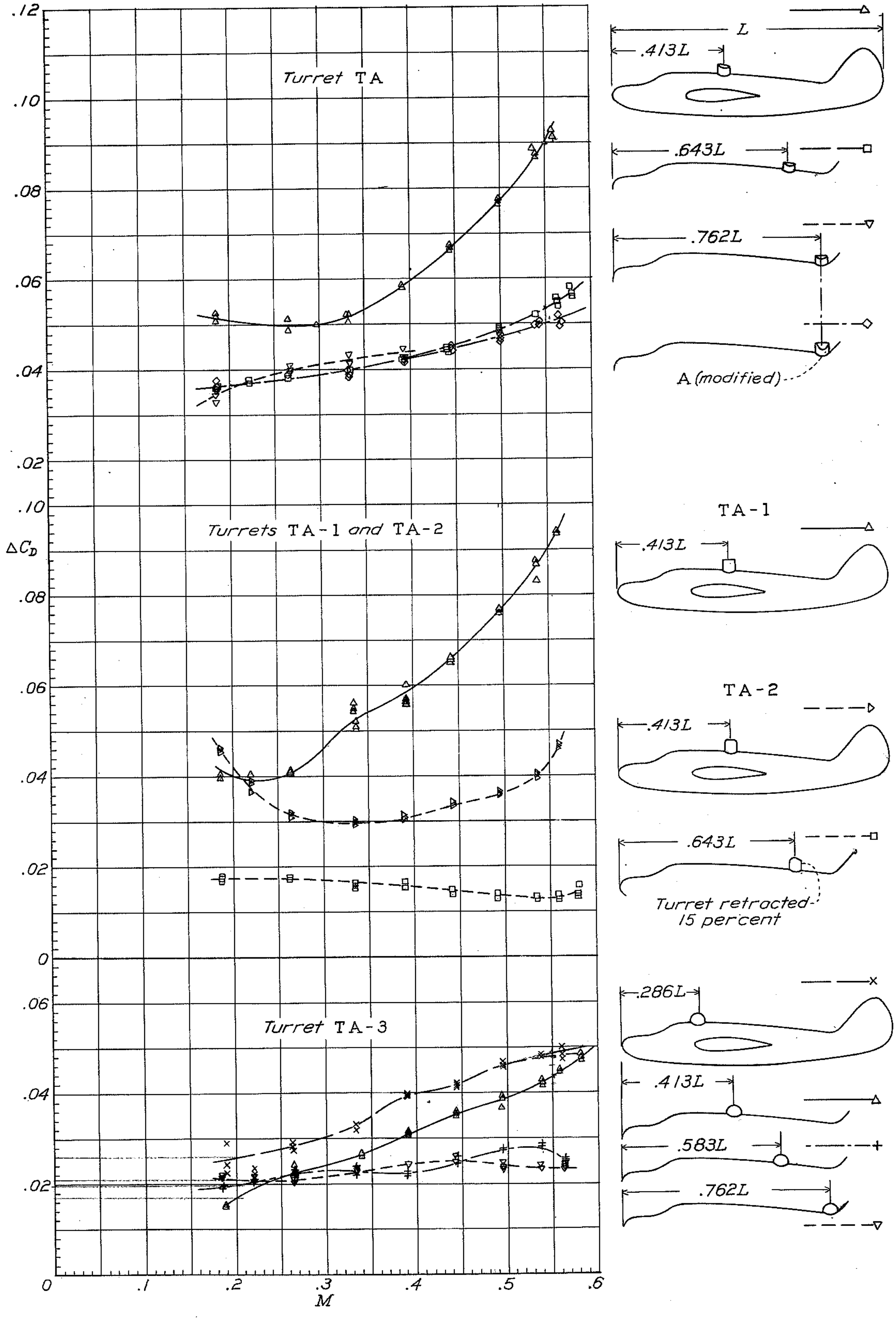

Figure 7.- Variation of incremental drag coefficient with Mach number for various locations of turrets on fuselage.

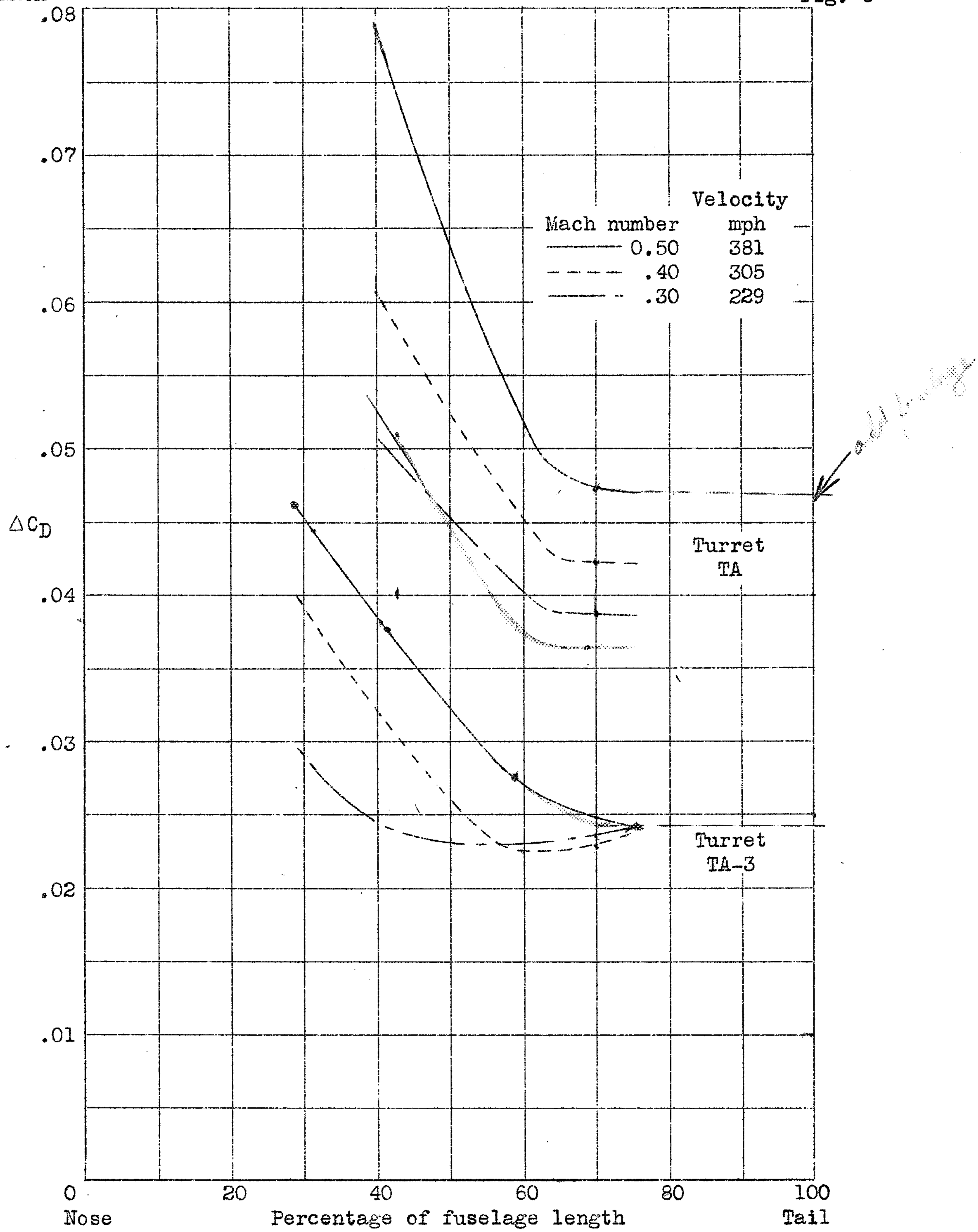

Figure 8.- Variation of incremental drag coefficient with location of turret on fuselage for two types of turret.

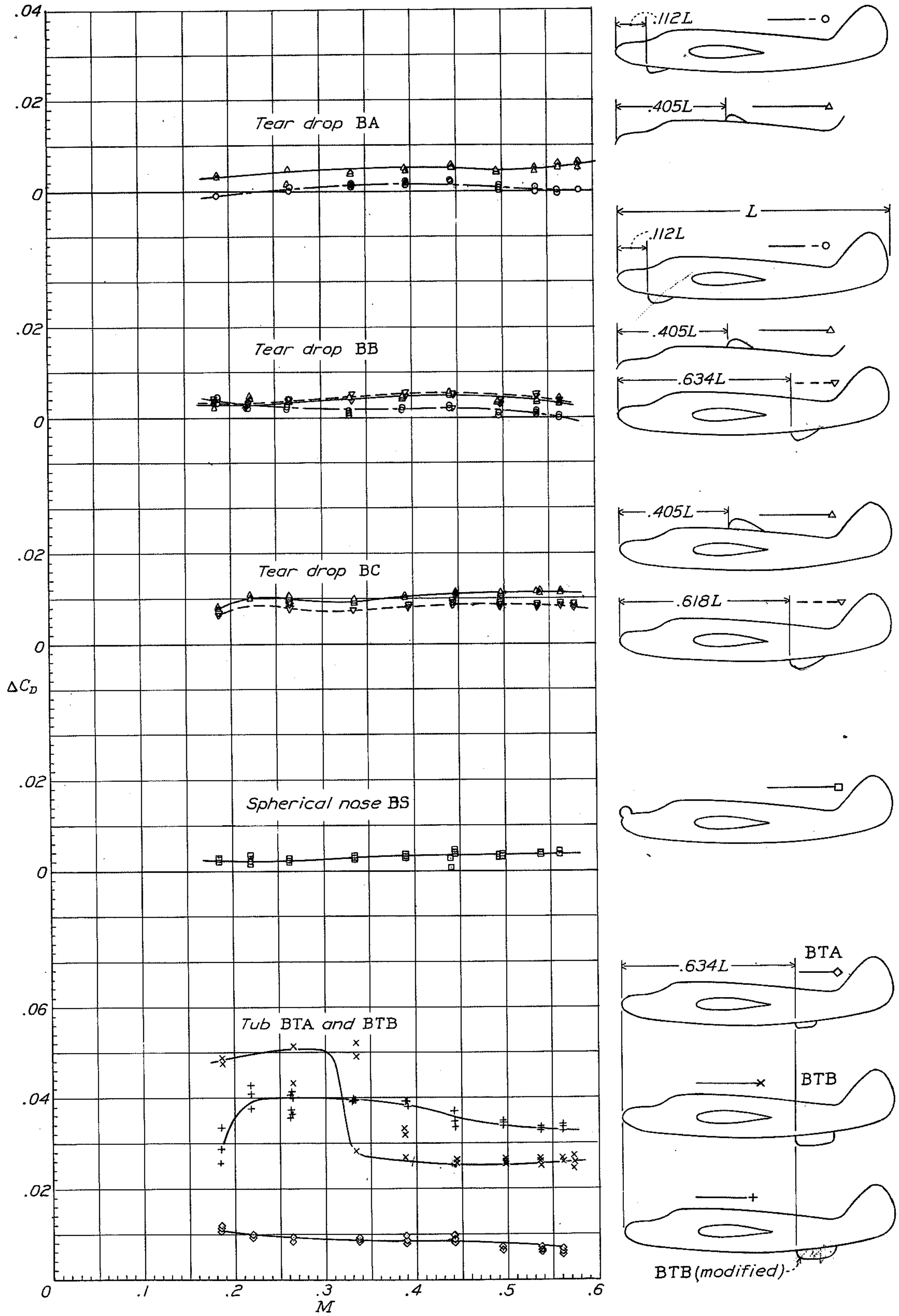

Figure 9.- Variation of incremental drag coefficient with Mach number for various types of blisters.

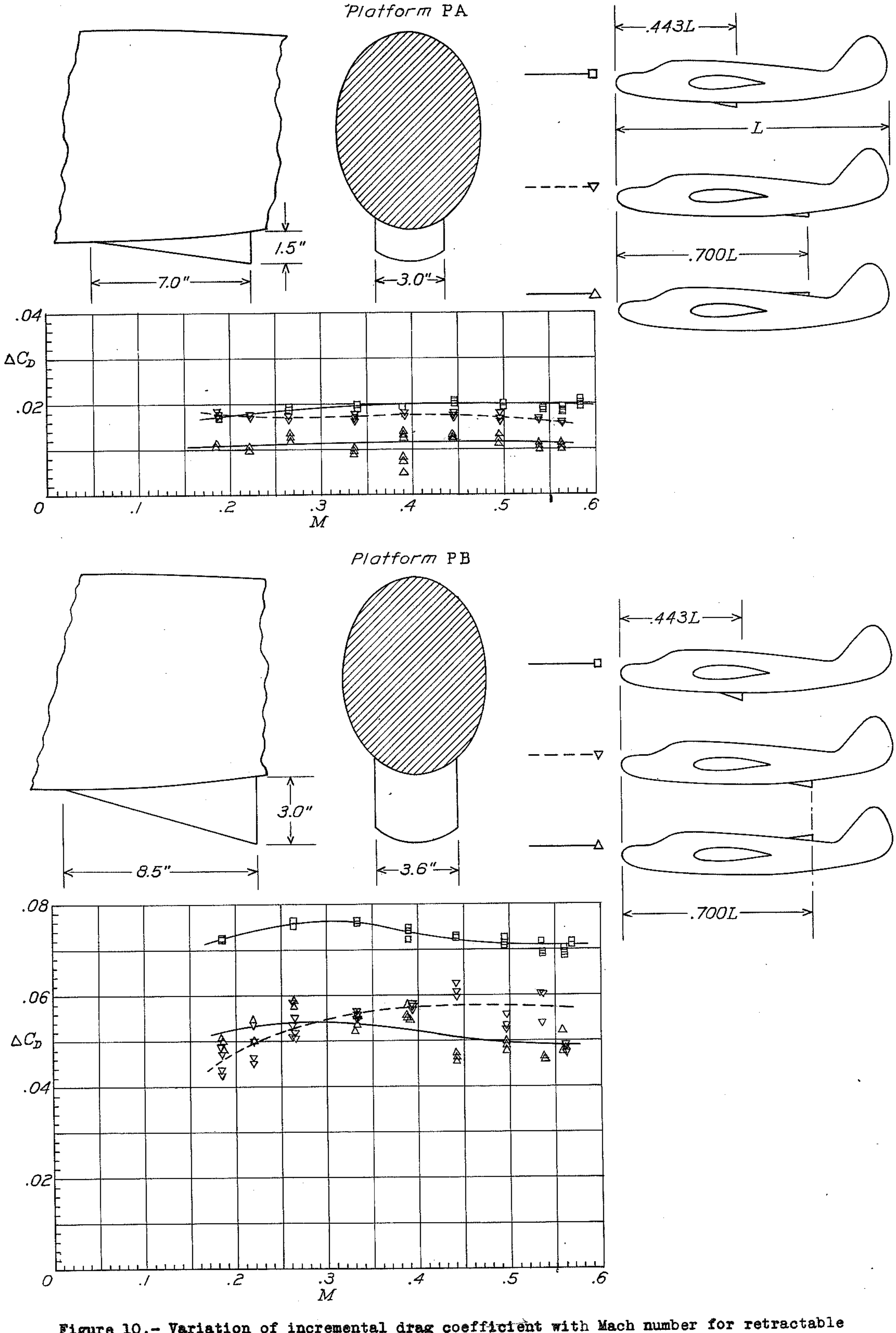

Figure 10.- Variation of incremental drag coefficient with Mach number for retractable rear-firing gunner's platforms PA and PB.

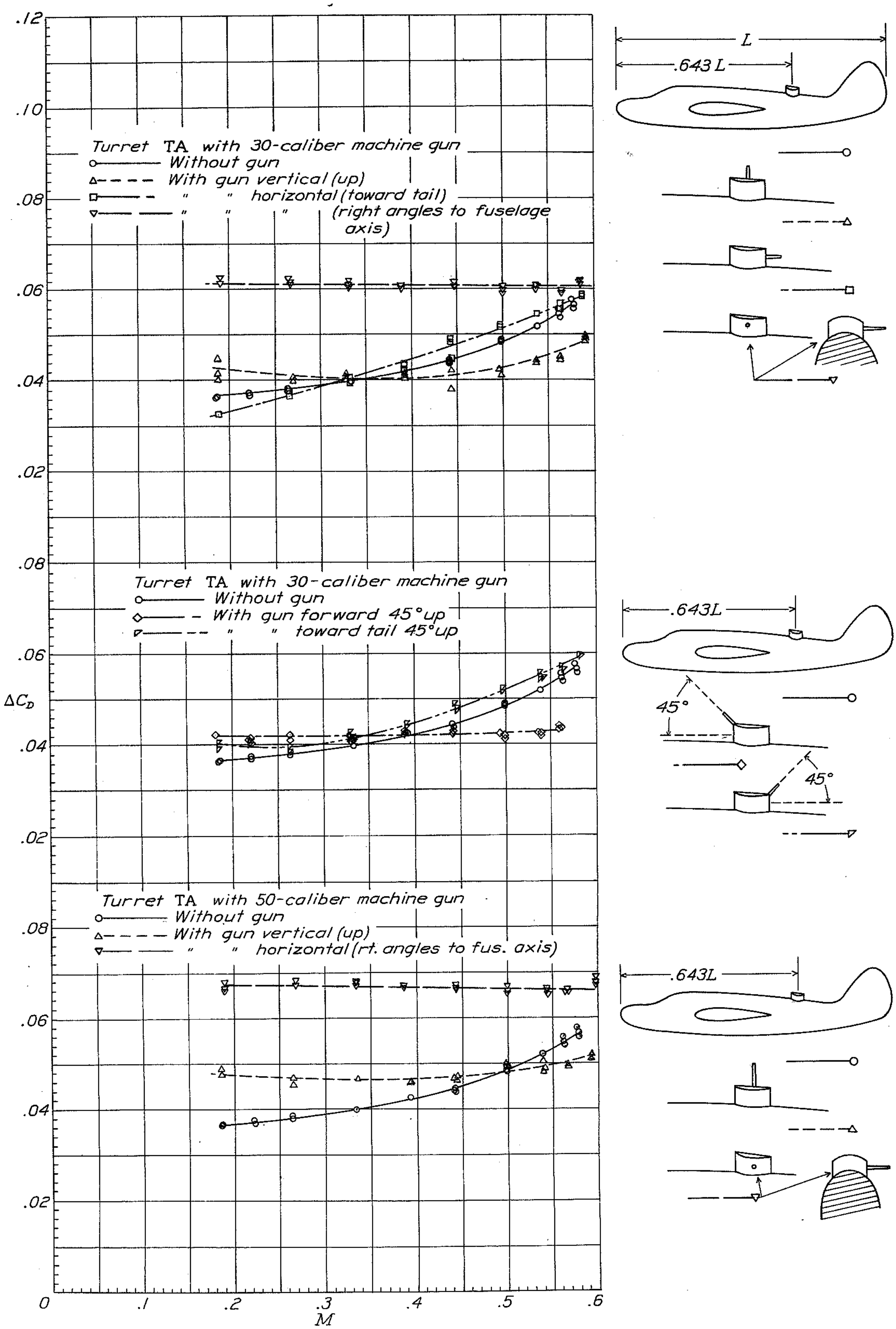

Figure 11.- Variation of incremental drag coefficient with Mach number for retractable cylindrical turret with protruding guns.

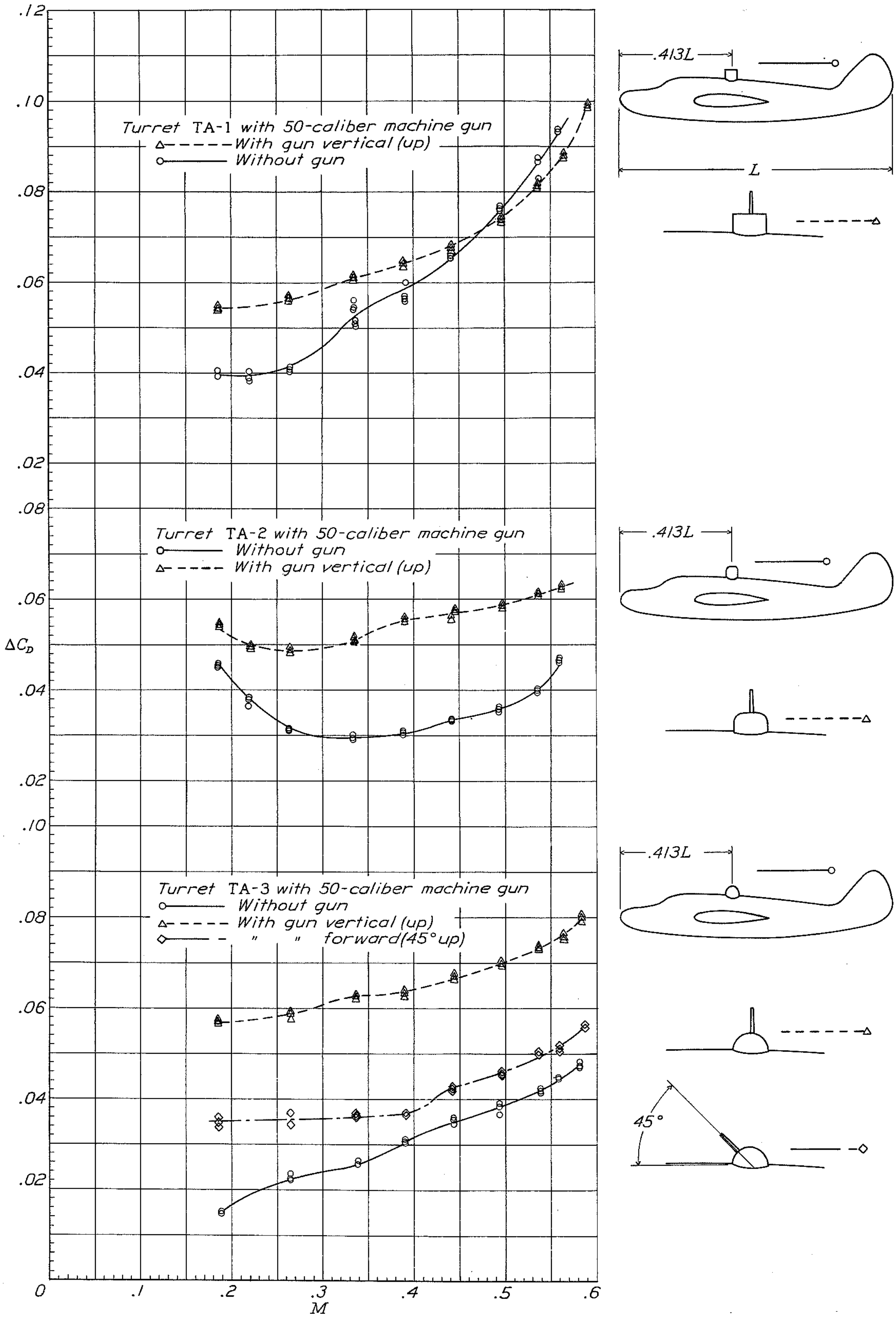

Figure 12.- Variation of incremental drag coefficient with Mach number for retractable turrets with protruding guns.

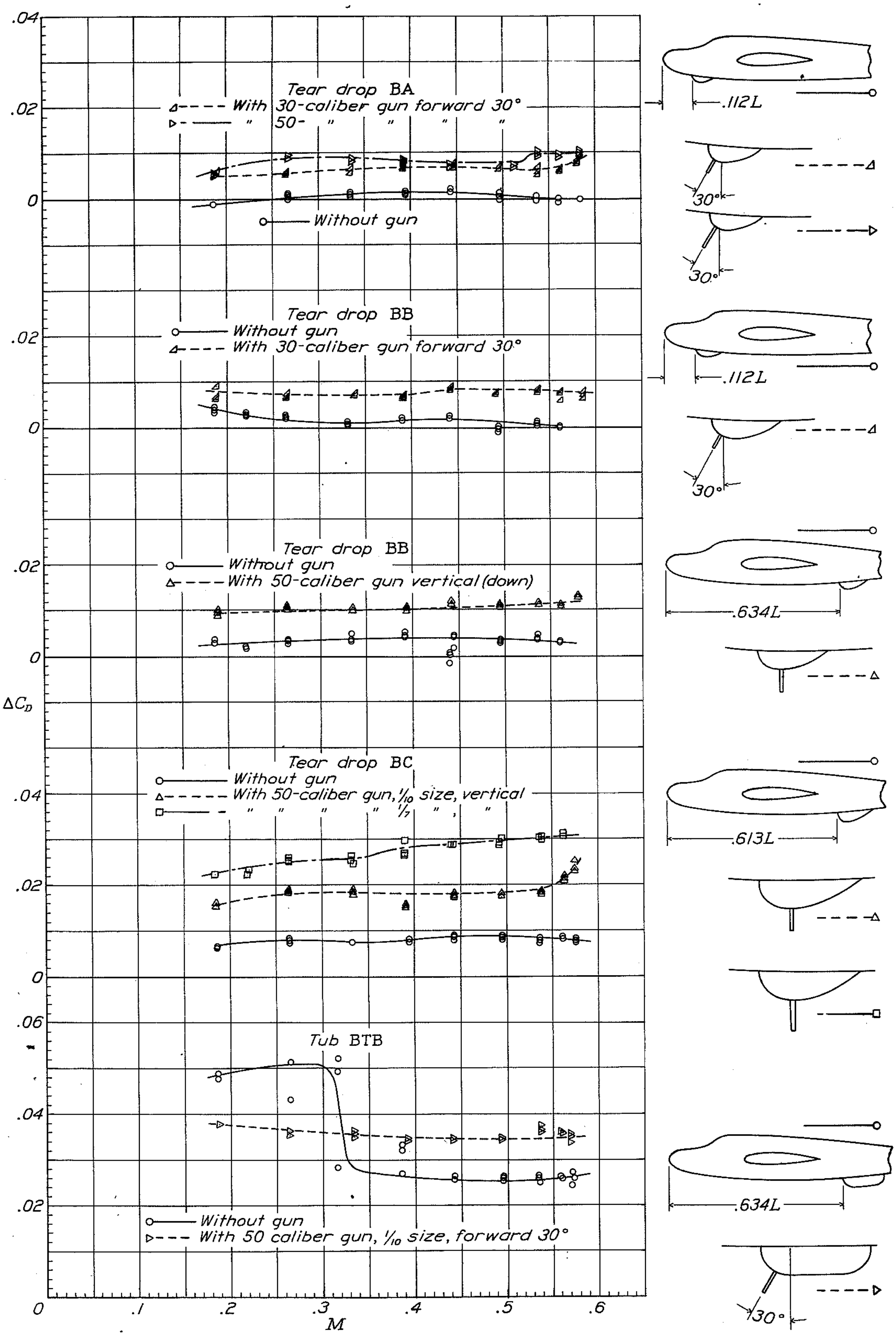

Figure 13.- Variation of incremental drag coefficient with Mach number for blisters with protruding guns.

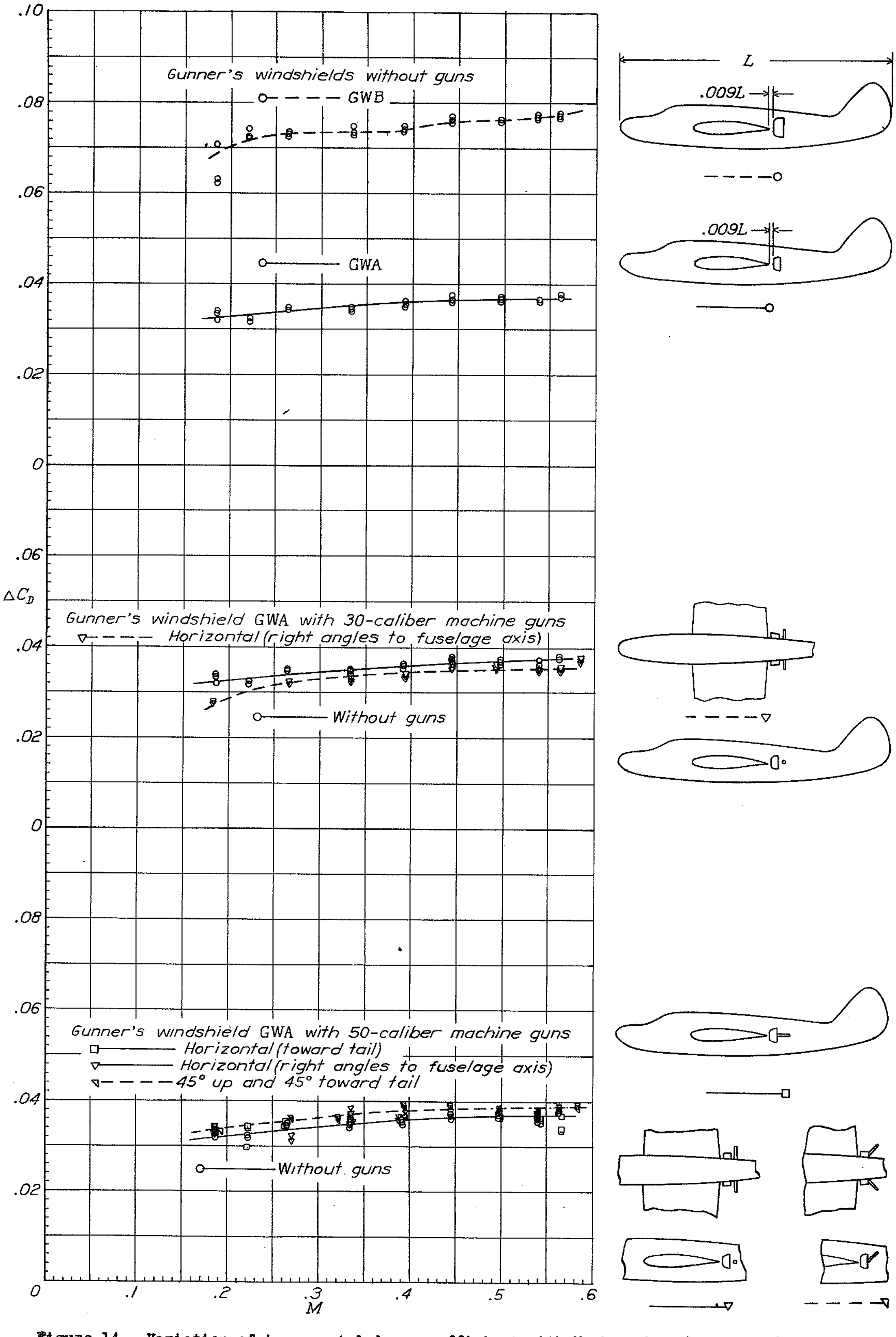

Figure 14.- Variation of incremental drag coefficient with Mach number for gunner's windshields with protruding guns.

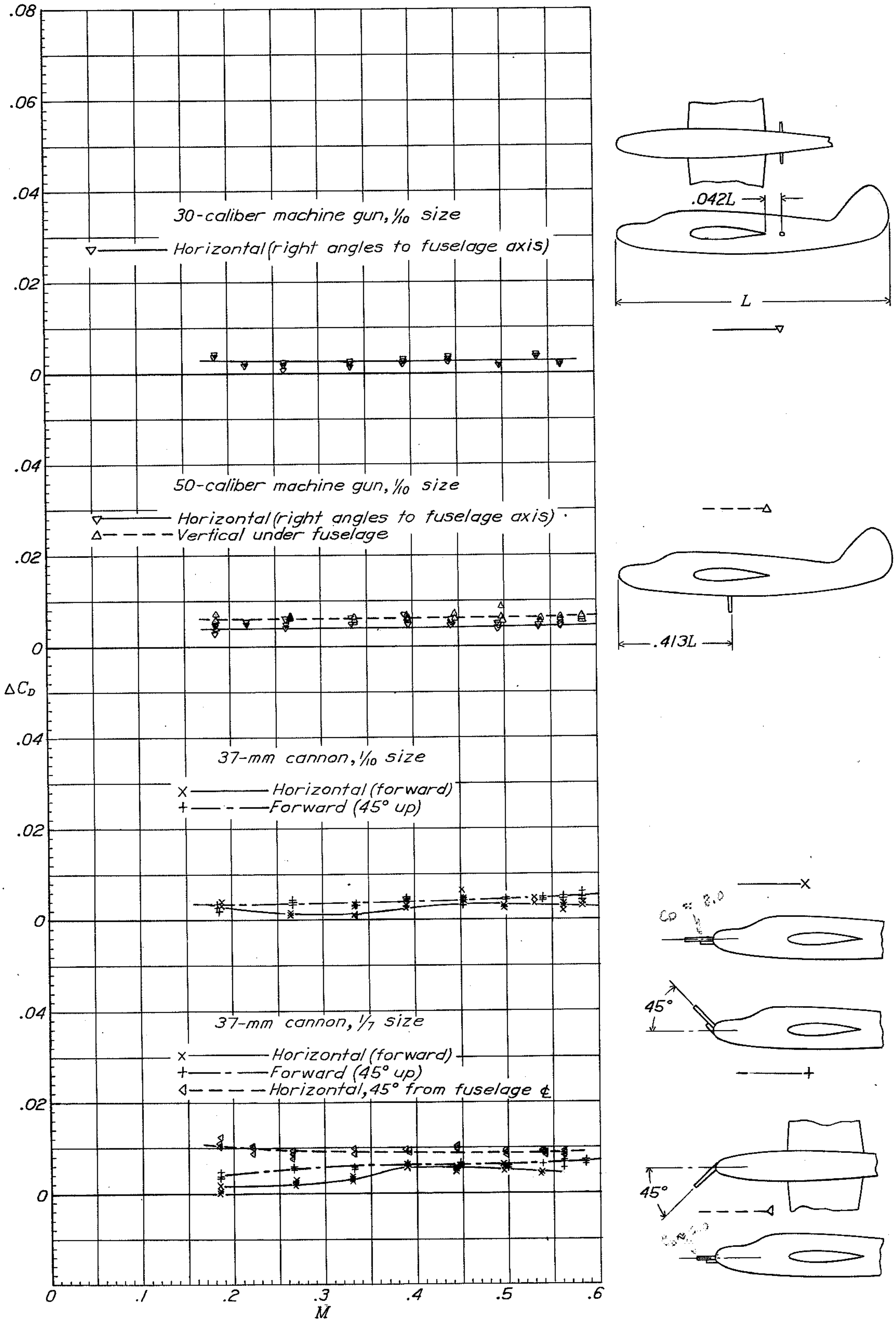

Figure 15.- Variation of incremental drag coefficient with Mach number for various types of protruding guns.