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SUBJECT NOTE ON THE EFFECT OF INTERCEPTOR PERFORMANCE ON KILL POTENTIAL

PREPARED BY R. J. Templin

ISSUED TO Internal

SUMMARY

In this note calculations are made of the probability of positioning interceptors of different performance so that successful missile firings can be made against bombers of subsonic and supersonic performance. It is concluded that effectiveness is greatly decreased if the interceptor suffers a speed disadvantage relative to the bomber, but that it is not greatly increased by a speed advantage, that a subsonic interceptor can be as effective as a Mach number two interceptor against a Type 37 bomber, and that the effectiveness of a supersonic interceptor is insensitive to differences in performance estimates.

1.0 INTRODUCTION

The Aerodynamics Laboratory was asked some time ago to provide information to DRB/CARDE, which would allow the performance of the Avro CF-105 all-weather fighter to be set up on an analogue computer for interceptor studies. The laboratory produced the required data in references 1 and 2.

CARDE had previously investigated the effectiveness of the CF-100 armed with Sparrow II missiles against a Type 37 bomber (the Russian 4-engine, pure jet, subsonic bomber). Their method of calculating system effectiveness of the fighter-missile combination is outlined in Reference 3. Presumably their corresponding study for the CF-105 is about to begin at the present time. Although the method is exceedingly tedious to apply in a thorough way, it is possible to use it for a few isolated cases which will give an approximate idea of the relative effectiveness of various weapons systems, without having to make use of a computer. It was felt to be of interest to make some calculations for the CF-105 in comparison with a subsonic fighter.

This laboratory has also been engaged for some time in an assessment of the performance capabilities of the CF-105, and there have been considerable differences of opinion with Company estimates. It has, however, been suspected that although large differences of performance are predicted, the effectiveness of the aircraft may not be greatly affected. This can be determined only by appropriate calculation.

A further reason for making such effectiveness calculations is to familiarize ourselves with the method used, and to learn what are the important factors in aircraft performance which make for high overall system effectiveness.

Accordingly, in this memorandum, the relative effectiveness of three different fighters is compared, against a Type 37 subsonic bomber, and also against an advanced bomber which is assumed to cruise at a Mach number of 1.3 at 50,000 feet. The three fighters are a good subsonic fighter (having performance somewhat superior to the CF-100), and two versions of the CF-105, one of which is a "conservative" CF-105, whose performance is as predicted by NAE, and the other is an "optimistic" CF-105 having Avro performance.

Since the CARDE method of estimating system effectiveness may not be familiar, it will be described briefly.

2.0 OVERALL SYSTEM EFFECTIVENESS

System effectiveness is defined as the probability of a single ready interceptor making a successful attack against a single bomber aircraft. It may be defined as the product of three probabilities: the missile salvo kill probabiliy P_K, the interceptor positioning probability P_P, and the aircraft reliability factor P_a.

The first factor, the salvo kill probability, is not the subject of this memorandum, and will be taken to be independent of interceptor performance characteristics. If P_K' is the single shot kill probability, then the salvo kill probability (for a salvo of n shots) is

$$P_K = 1 - (1 - P_K')^n$$

The single shot probability, P_K', is itself the product of a number of other probabilities, such as the probability the missile will function correctly, the reliability of the fuse, and the warhead lethality.

In the CARDE CF-100 study, the value of P_K' for the Sparrow II was taken to be 0.288, and hence for a salvo of four missiles, the salvo kill probability is 0.74. Allowance was made for occasional shielding of missiles by the airframe during launch, and the above figure was accordingly lowered to 0.70. This figure will be retained in the present memorandum.

Another probability which will be assumed to be the same for all interceptors is the aircraft reliability factor P_a, which will be taken to be 0.75, as was assumed by CARDE for the CF-100.

The main subject of the present memorandum is the calculation of the aircraft positioning probability P_P, which is defined as the probability that a serviceable aircraft can be directed by ground control and its own radar to the missile launching zone in such a way that the successful launching of a salvo of missiles can be made. The method of calculation will now be outlined. A more detailed account is to be found in Reference 3.

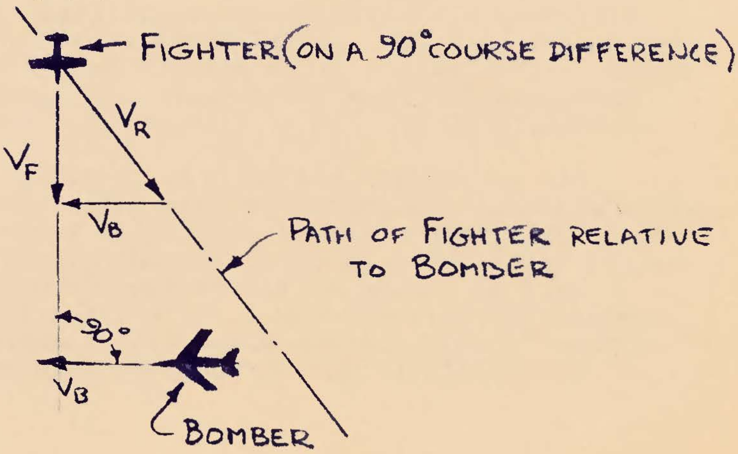
3.0 METHOD OF CALCULATION OF INTERCEPTOR POSITIONING PROBABILITY

In the initial phase of interception, a fighter is directed towards the bomber by ground control. The bomber and fighter are located by means of ground radar. The ground controller attempts to direct the fighter in such a way that it will be in an optimum position to complete the attack at the time it makes contact with its own AI radar. At this time the fighter begins to manoeuvre, if necessary, in order to launch its missiles accurately enough to obtain a kill.

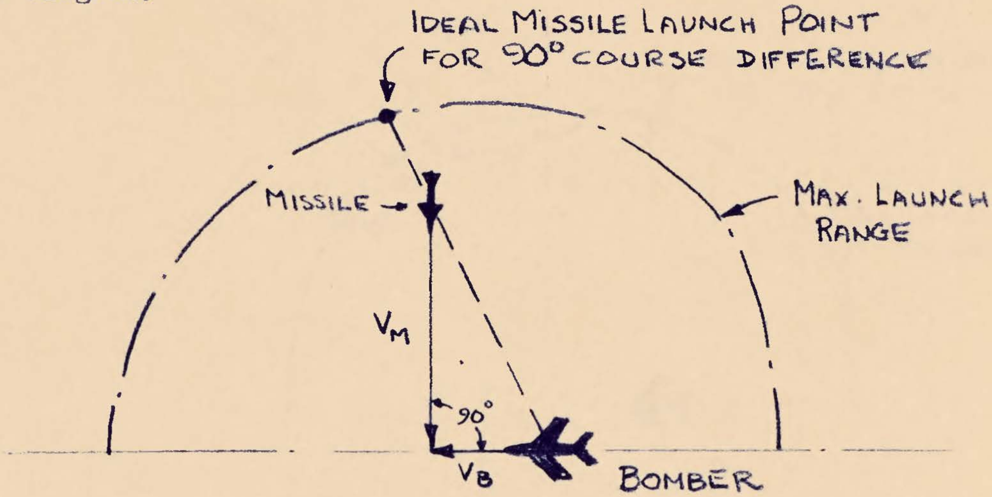
If the bomber is flying at steady speed in straight, level flight, and the fighter is approaching on a particular course relative to that of the bomber, there is one "ideal" approach path for which the fighter will not have to manoeuvre at all, and can launch missiles at their maximum range so that the missiles will be on a collision course with the bomber. If the fighter continues on this course without turning it will eventually pass astern of the bomber, and for this reason such a course is called a "lead collision" course. However, the fighter does not have to be on this course to ensure success. If it is approaching either ahead of or behind the ideal position, it may still launch missiles at maximum range and, provided the launch is made within some allowable heading error, the missile itself can carry out all necessary corrections.

There is, however, an extreme "early" and an extreme "late" position of the fighter beyond which the combined manoeuvrability of the fighter and its missiles will not permit a successful attack to be carried out.

It is convenient, at this point, to view the situation in bomber co-ordinates. That is, from the point of view of an observer in the bomber. This is a little difficult to visualize at first, but makes the geometry of the situation simpler. Suppose the fighter approaches the bomber on a 90° course difference. Its path relative to the bomber will be in a direction given by the resultant velocity vector, as shown in the diagram below:

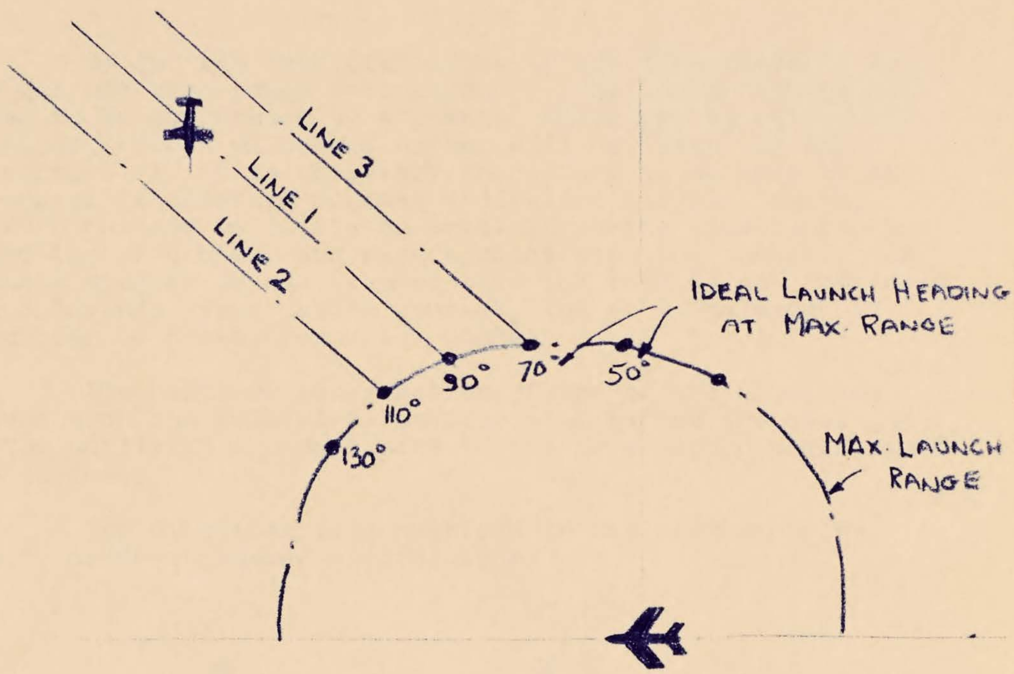


There is a certain contour surrounding the bomber, which is the maximum missile launch range. If the missiles were launched at this range in such a way that they could continue on their course and collide with the bomber without having to manoeuvre, there is a particular point at which they would have to be launched. This point can be determined from another vector diagram.



For each course difference (of the fighter and missile relative to the bomber) there will be a different ideal launch point on the maximum range contour. These points can be found graphically as shown above, and labelled with the course difference. Now these are "ideal" launch points, from which the missile can proceed to collision without having to manoeuvre. Actually some latitude is allowable because of missile manoeuvrability. Suppose a launch heading error of $\pm 20°$ is allowable at maximum launch range. The diagram below illustrates this situation, for a fighter approaching at 90° course difference.

The "ideal" approach path of the fighter is line 1 in the diagram. On this path, the fighter would reach the maximum launch range at 90° course difference to the bomber, and if it then launched its missiles, they would be on a collision course. If, however, the fighter approached further ahead, at line 2, without manoeuvring, it could still launch missiles at maximum range because the missile itself could correct the 20° heading error. Similarly line 3 represents the rear limit of such an approach.



There is also a minimum missile launch range contour at which the missiles must be launched with zero heading error because there is not sufficient time left for them to manoeuvre. If the fighter approaches further ahead of line 2 or further behind line 3 in the diagram above, it must manoeuvre sufficiently to reduce the launch heading error to 20° at maximum launch range, or if this is not possible, it must continue turning in the hope of reducing the heading error to zero by the time minimum launch range is reached.

If the aircraft is ahead of line 2 it must turn to port, and this turn must commence at a point which depends on the distance of the approach path from line 2. The locus of all such points is called a "manoeuvre barrier". There is one manoeuvre barrier by which the aircraft must start to turn in order to reduce the launch heading error to 20° at <u>maximum</u> launch range, and another barrier by which it must turn in order to reduce the heading error to zero at <u>minimum</u> launch range.

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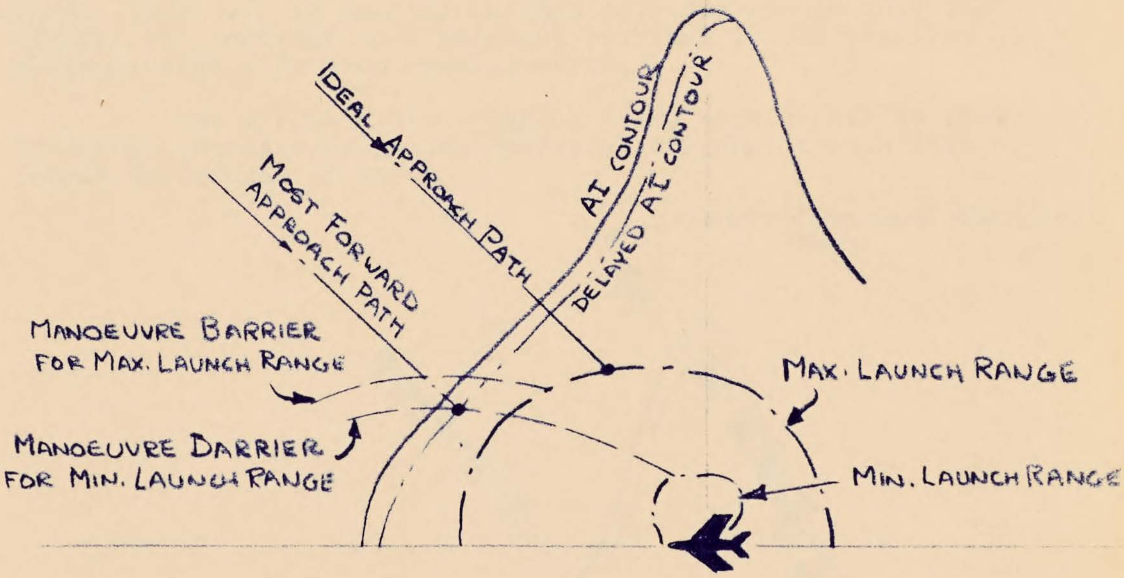
So far the characteristics of the interceptor's A.I. radar has not been taken into account. The bomber can be considered to be surrounded by a contour which may be called the AI contour, within which the bomber will be "seen" by the interceptor. If it is necessary for a turn to be made by the interceptor in order to achieve successful missile launch, this turn can not be initiated until after the interceptor has crossed the AI contour and made contact with the bomber. In the CARDE studies it was assumed that the turn is not initiated until 3 seconds after making contact, and so a "delayed" AI contour can be drawn around the bomber.

The point of intersection of one of the manoeuvre barriers with the delayed AI contour will define the most forward (or earliest) approach path of the interceptor which would allow success.

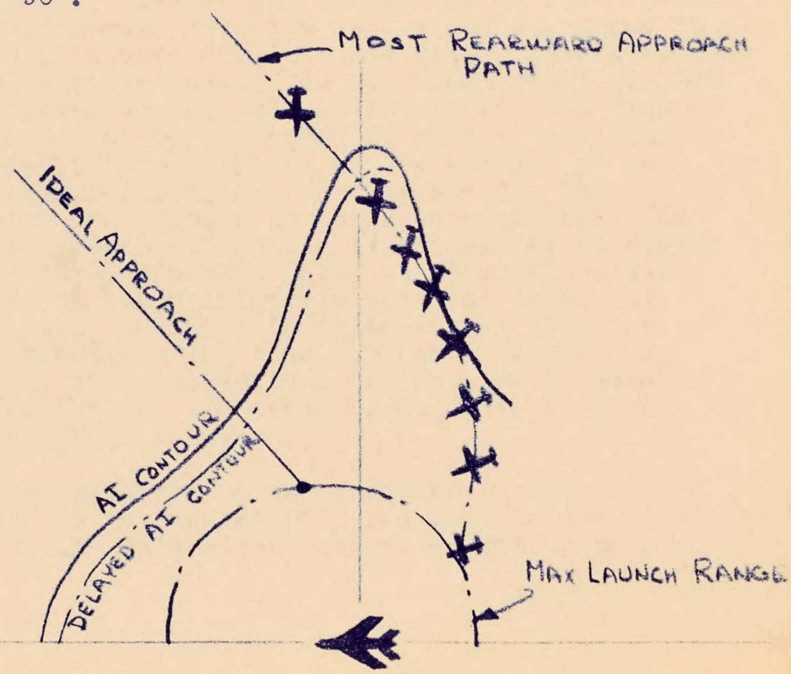
The situation is summarized in the diagram below, which is drawn in bomber co-ordinates.



In the diagram, the manoeuvre barrier for minimum launch range is shown as the governing one because its intersection with the delayed AI contour will give the widest possible approach lane for the interceptor. In this case a fighter approaching along the most forward path would initiate a port turn 3 seconds after AI contact, and would find it necessary to continue turning until minimum launch range is reached, at which time its missiles would be heading on a collision course with the bomber.

In a somewhat similar manner the most rearward limit of the approach lane can be graphically determined, but in this case other factors determine the limitations. If the interceptor suffers a speed disadvantage relative to the bomber it must not fall too far back while making its necessary starboard turn, because it will not be able to catch the bomber. If the interceptor speed is equal to or greater than that of the bomber such a limitation disappears but it may still be the case that the bomber penetration may be unacceptably high by the time the interceptor catches up. However, rather than impose an arbitrary limitation of this type, and in order to simplify the calculations, it was assumed in the present study that the rearward limitation is given by the condition that the interceptor, on entering the AI range contour, must not pass out of it again (and hence lose contact) while making its starboard turn. This turn is carried through only far enough that the fighter can continue on a straight path and launch missiles at maximum range with zero heading error.

The approach of a fighter along such a path is shown in bomber coordinates in the following diagram, for an initial course difference of 90°.



By these methods it is possible to determine graphically the allowable approach lane width for the interceptor, for any given initial course difference. One possible further limitation has not yet been mentioned, and was in fact ignored in the present study; some of the manoeuvres required of the interceptor may put it into a position and attitude relative to the bomber such that its radar look angle limitations are exceeded. This factor was ignored because these limitations were not known for the CF-105.

Another limitation of this study is the fact that the calculations have been carried out only for a 90° initial course difference between the fighter and bomber. The calculations are somewhat tedious and in any case it was found by CARDE in the CF-100 study that this course difference is not far from the value which gives maximum positioning probability. For these reasons no further cases were considered. A thorough analysis, however, could not ignore this variable.

When the allowable approach lane has been determined, it remains to calculate the probability that the interceptor can be successfully positioned within it by the ground controller. The reason why this event is a probability rather than a certainty is that ground-based radar is not by any means a precision measuring device. It shows the positions of aircraft in an intermittent fashion and subject to other uncertainties. When the ground controller assumes the fighter to be in a certain position and on a certain path relative to the bomber, there is a probability that this is correct, but also some probability that the fighter is almost anywhere else. In the CARDE study the RMS position uncertainties are worked out separately for the fighter and for the bomber, and then superimposed to give a resultant RMS uncertainty of the fighter relative to the bomber. A two-dimensional Gaussian distribution is then assumed for the position probability of the fighter in bomber coordinates. If it is assumed that the ground controller is attempting to direct the fighter along the ideal approach path, the Gaussian distribution is superimposed on the permissible approach lane, and centred on the ideal path, and then integrated over the lane. This will give the probability that the fighter will actually be somewhere within the permissible lane at the time it makes radar contact with the bomber. In other words, this integral is the positioning probability P_P.

The R.M.S. uncertainty of the position of the fighter relative to the bomber is not necessarily the same in the direction of bomber motion as in the lateral direction, depending on a number of factors. If the bomber is approaching the ground radar, the lateral uncertainty is greater, and may be further increased by dog-leg confusion manoeuvres, during which the bomber changes course to both sides of its mean direction. In the present memorandum, the additional uncertainty due to random dog-leg manoeuvres has not been taken into account, and the RMS uncertainties of the fighter relative to the bomber have been taken to be those given in Reference 3 with no dog-legging. They are as follows:

RMS uncertainty parallel to bomber path = ±4630 yards

RMS uncertainty at right angles to bomber path = ±9450 yards

4.0 BOMBER PERFORMANCE

Two different types of bomber were assumed in the analysis. The first, a subsonic bomber having performance comparable to the 4-jet Type 37, was assumed to fly at M = 0.75 at 50,000 feet.

The second bomber was assumed to be supersonic, flying at M = 1.5 at 50,000 feet.

5.0 MISSILE PERFORMANCE

The missile launch range contours were copied from those used in Reference 3. It was assumed that missile velocity was constant at 2000 ft./sec., when fired from a subsonic fighter, and 3000 feet/sec. from a supersonic fighter. This choice was somewhat arbitrary, but as a matter of fact it can be shown that the results are quite insensitive to these quantities. An allowable launch heading error of ±20° was assumed at maximum launch range.

6.0 FIGHTER AI RADAR PERFORMANCE

The AI contour around the bomber was copied from Reference 3. It presumably applies to an AI radar set which is somewhat inferior to that actually intended for the CF-105, but the characteristics of the CF-105 system are unknown here, and in any case the purpose of the present approximate analysis was to compare the capabilities of the CF-105 with a good subsonic fighter, both carrying the same equipment, and so although the absolute value of the results may be affected by this assumption, the comparison probably is not.

7.0 FIGHTER PERFORMANCE

As was pointed out in the Introduction, three different fighters were investigated. They are referred to as Fighters A, B and C in what follows.

Fighter A is a subsonic fighter, which is assumed to fly always at a Mach number of 0.75 at 50,000 ft. (Note that this is the same as was assumed for the subsonic bomber). At this speed and altitude it is assumed to be capable of a sustained load factor of 1.2 g's. This permits it to make a steady level turn of about 4.7 miles radius. A plan view of this turn is found in Figure 1.

Fighter B is a supersonic fighter. Its performance in turns is that which is calculated by the NAE for the CF-105, when its centre of gravity is at 28% of the mean aerodynamic chord. As such, its performance is considerably inferior to that estimated by Avro. In the present study it is assumed to fly at a Mach number of 2.0 at 50,000 ft. when in straight flight. In actual fact the NAE aerodynamic estimates indicate that the CF-105 has a maximum level speed at this c.g. position which is somewhere between 1.9 and 2.0, but it was felt for the present purposes that a slight upgrading in level speed performance would have a negligible effect on the results. This aircraft then enters a combat turn at a Mach number of 2.0. Examples have been calculated for several types of turn to determine what is the best method. It is found that in general, if time to turn is the most important quantity, and if also it is considered undesirable to lose speed, then it pays to apply only moderate load factor at first, but to overbank to 90° so that the nose of the aircraft drops. In the descending turn a much greater load factor can be applied and finally the angle of bank is greatly reduced so that the aircraft pulls out of its moderate dive. In this manoeuvre it will suffer a considerable loss in altitude, and probably the method would be useful only if the fighter is required to make a large change in course ending in a tail chase with the bomber. In such a case altitude could be regained, if necessary, at a slow rate without reducing speed.

If it is important not to lose altitude, but not as important to maintain high speed, then it seems preferable to apply a large load factor and to control angle of bank so that there is no loss in altitude. In this case the speed of the aircraft will drop in the turn. The present study of the positioning problem shows that loss of speed in the turn is actually an advantage because it shortens the turning radius. Accordingly, constant altitude decelerating turns were adopted. It was also decided to assume that these are carried out at a load factor of 3. At this value, Fighter B decelerates rapidly, and has reached a Mach number of 1.3 after making a turn of about 90°. Probably it would be undesirable to continue this turn because the aircraft is rapidly approaching a buffet condition. Accordingly the remainder of the turn was assumed to be carried out at a constant Mach number of 1.3, at the maximum steady load factor (which is 1.305). As a matter of fact turns of greater than 90° were not required for the interception cases studied, and so the last assumption above is of academic interest only. A plan view of a 180° turn of this type for Fighter B is also shown in Fig. 1. The average radius of turn for the first 90° is about 6 miles, but increases to about 11 miles after the speed has dropped to 1.3.

Fighter C is another version of the CF-105. Again, it is assumed to fly at a Mach number of 2.0 in straight flight, and to carry out level turns at a steady load factor of 3. However its aerodynamic characteristics are those estimated by Avro, and in addition its centre of gravity is assumed to be set back to 34 percent of the chord. (This is several percent further back than it is likely to get in practice). Because of the much lower trim drag at high lift, Fighter C decelerates much more slowly in turns. The Mach number has dropped to about 1.9 after 90° of turn, and to about 1.77 after 180°. The mean radius of turn is about $7\frac{1}{2}$ miles for the first 90° and about $6\frac{1}{2}$ miles for the second 90°. A plan view of this turn is shown in Fig. 1 for comparison with those of Fighters A and B.

One of the things which is felt strongly in carrying out such calculations, is the extreme "sluggishness" of a Mach number 2 fighter in comparison with its subsonic cousin. The above calculations show that the radius of turn of the supersonic fighters is greater than that of Fighter A, although their turns are made at a load factor of 3 g's (an angle of bank of 70°), while Fighter A turns at only 1.2 g's. This is also shown in other manoeuvres. In a descending turn of the type described above, Fighter C banks initially to 90° and holds this until the nose has dropped 20 degrees, while pulling as much load factor as is required to prevent an increase in speed. Initially the load factor is 2.28. As the nose drops this increases to about 5 g's. Even at this extreme angle of bank it takes over 20 seconds for the nose to drop 20 degrees. At this point the angle of bank is greatly reduced to produce a vertical acceleration and the aircraft begins to pull out of its dive. It will have accomplished the pull-out in another 20 seconds, but will have lost a total of about 14000 feet of altitude and will have nearly completed a 180° turn. The procedure does, however, shorten the mean radius of turn to about 5 miles (from about 7 miles).

Another case which was calculated for Fighter C was a pull-up from level flight at M = 2.0 at 50,000 feet. The pull-up was carried out at 3 g's and was terminated when the flight path had reached a 20 degree slope, after which the aircraft was allowed to round off at a load factor of zero (a ballistic trajectory). It required about 9 seconds at 3 g's to reach a 20° nose-up flight path and after 27 seconds the top of the trajectory had been reached at about 58,000 feet. The total distance covered by the aircraft was about 9 miles and its Mach number had decreased to 1.68 at the top.

As will be seen, this sluggishness may almost completely cancel any benefits of high speed in interception manoeuvres against a subsonic target.

8.0 PLACEMENT DIAGRAMS

The first step in calculating the positioning probability for a given fighter approaching the bomber on a given initial course difference, is to determine the allowable width of the approach lane. This is done graphically on a "placement diagram".

Figure 2 shows the placement diagram for the subsonic bomber. The allowable approach lanes for all three fighters are shown. It will be noticed that there is not a great deal of difference in the width of these lanes for the three aircraft, and hence it is not to be expected that there will be much difference in their positioning probabilities. These lanes, of course, apply only for a 90° course difference between fighters and bomber.

Figure 3 is the corresponding placement diagram for the supersonic bomber. In this case it is obvious that the capabilities of the subsonic fighter are seriously reduced, and the main reason is that the rear limit of the approach lane is cut down. A fighter approaching on the rear limit must make a turn to come in on the bomber's tail quarter, and the scope of a subsonic fighter is therefore severely limited against a supersonic bomber. On the other hand, the approach lanes for the supersonic fighters are not greatly different from those of Figure 2.

In nearly all cases, the "ideal" approach path (the lead-collision course) is not located at the centre of the lane, and if the ground controller is attempting to direct the fighter along this path, there is a higher probability that the attack will fail due to the fighter being too far forward than too far back. One solution may be for the ground controller to purposely attempt to direct the fighter on a more rearward course, but the optimum amount of the shift would be different for different approach courses. It follows also that greater fighter manoeuvrability would improve the chances of successful attack if the fighter must turn on to the bomber nose, but would not greatly help for turns into the rear quarter.

It will be noticed also from these placement diagrams that Fighter B appears to have a slightly wider permissible approach lane than Fighter C, and hence that its positioning probability is greater. This is due to the fact that the mean radius of turn of Fighter B is less than that of Fighter C if they both turn at the same load factor. Fighter B is the "pessimistic" CF-105, as far as aerodynamic estimates are concerned, and thus the paradox arises that the fighter with the higher drag seems better in combat. This comparison is hardly fair, because there are several ways in which Fighter C could have equalled the manoeuvrability of Fighter B. For example it could throttle back in the turn in order to decelerate more rapidly. This, however, might increase the risk of afterburner blowout. Alternatively it could turn at higher load factor, but it would soon run into elevator hinge moment limitations. It could also open dive brakes, if it had any. The latter arrangement is probably the most flexible. The CF-105 has dive brakes, but at the moment they are incapable of being safely opened at supersonic speeds.

9.0 CALCULATION OF POSITIONING PROBABILITY

As outlined in Section 3, the method of calculating positioning probability is to superimpose the assumed positioning uncertainty distribution on the allowable approach lanes, and to integrate it over the lane width. The uncertainty distribution is centred on the ideal approach path on the assumption that this is the path along which the ground controller is attempting to direct the fighter. For an RMS uncertainty of the fighter relative to the bomber of ±4630 yds. parallel to the bomber path and ±9450 yds. at right angles to this path (See Section 3), the calculated positioning probabilities are as shown in the table below. The overall system effectiveness was defined in Section 2 to be the product of the positioning probability Pp and two other probabilities P_K and P_a which were assumed to be equal to 0.70 and 0.75 respectively. Hence the overall system effectiveness is obtained by multiplying the positioning probability by 0.525. System effectiveness is also listed in the table below.

TABLE I

POSITIONING PROBABILITY P_P, AND SYSTEM EFFECTIVENESS P_P P_K P_a

50,000 feet, co-altitude attacks, with 90° initial course difference between fighter and bomber.

	Subsonic Bomber M=0.75		Supersonic Bomber M=1.3	
	P_P	$P_P P_K P_a$	P_P	$P_P P_K P_a$
Fighter A	0.87	0.456	0.425	0.223
Fighter B	0.90	0.472	0.79	0.415
Fighter C	0.885	0.465	0.775	0.407

10.0 DISCUSSION OF RESULTS

The above results indicate that Fighter A (a subsonic fighter) can be nearly as effective as the supersonic fighters against a subsonic bomber aircraft. The positioning probability (0.87) for Fighter A is somewhat greater than the corresponding value for the CF-100 aircraft as obtained by CARDE in Reference 3. Their values ranged from about 0.7 to 0.8. In the CARDE study, the bomber was allowed to carry out dog-leg manoeuvres to increase the lateral positioning uncertainty, and also the limitations due to AI radar look angle were taken into account. However, an even greater effect was that due to the speed disadvantage (about 30 knots) of the CF-100 relative to the Type 37 bomber for co-altitude attacks. CARDE extended their study to investigate the effects of carrying out attacks from altitudes 5000 feet and 10,000 feet below that of the bomber, and making use of the missiles' jump-up capabilities. These altitude differences wipe out the speed differential between fighter and bomber, and considerably increase its chances of success. If the fighter suffers a speed disadvantage, attacks which require a turn on to the rear of the bomber are limited by the maximum allowable fall-back of the fighter, and in this case the rear limit of the allowable approach lane will be cut down. The low positioning probability of Fighter A against a supersonic bomber illustrates this point.

On the other hand the present study indicates that a speed advantage (even a large one) is no great advantage to the fighter if it results in a reduction in manoeuvrability. In Figure 2, it will be noticed that the rear limit of the approach lane for Fighter A is so close to the extreme width of the AI contour, that there is very little improvement to be obtained by an increase in speed. The forward limit of the lane, on the other hand, is mainly affected by manoeuvrability, and in particular by radius of turn.

These conclusions are the result of an approximate analysis which was carried out for one particular course difference only. A more thorough analysis, covering course differences from zero to 180° may modify them somewhat, but it must be remembered that the approach course to be used is, to some extent, the choice of the ground controller, provided there is sufficient warning time, and hence all course differences are not equally probable.

To weigh the advantages of interceptor speed only from the point of view of final combat is not, of course, the fully story. Extra speed permits the interception to be carried out at shorter bomber penetration, for a given warning distance, provided that the fighter radius of action is large enough. Since supersonic fighter radius of action would normally be less than that of a good subsonic fighter, it may not always be possible to realize this potential advantage.

One conclusion from this analysis is that it might be worth while to carry out a short project study of a high altitude subsonic, all-weather fighter. It would undoubtedly be an aircraft considerably larger than, say, the F-86, because of the need to carry sophisticated fire control equipment, but it might not be much larger than the CF-100. Its design would be considerably simpler than that of a supersonic fighter for several reasons. Supersonic stability and control problems would not arise. External missile stowage would probably be feasible without seriously affecting performance. Its wing loading would probably be low because of the high-altitude manoeuvrability requirement, and this would make for good landing and take-off characteristics. Its thrust-to-weight ratio probably would have to be high for the same reasons, and this might make it worth while to consider a VTO version. A very preliminary guess points toward an aircraft in the 30,000 lb. class powered by a single Orenda Iroquois, and armed with 4 Sparrow missiles. The results of such a project study could be used in a complete weapons system evaluation such as that now being undertaken by CARDE for the CF-105.

It should be borne in mind that any subsonic fighter would be relatively helpless against a supersonic bomber

11.0 CONCLUSIONS

On the basis of this approximate analysis, it is concluded that,

1. The overall system effectiveness of a supersonic interceptor armed with air-to-air missiles is insensitive to differences in interceptor performance estimates.

2. Effectiveness is greatly reduced if the interceptor suffers a speed disadvantage relative to the bomber, but changes very little as the interceptor speed is increased above that of the bomber, as long as the interceptor radius of turn is not changed.

3. A subsonic fighter whose performance is at least equal to that of the bomber may be nearly as effective as a Mach number two fighter, provided the same armament is carried.

4. The manoeuvrability and hence the effectiveness of a supersonic fighter could be improved if it carried dive brakes which could be operated at supersonic speeds.

5. There may be some point in carrying out a project study of a high-altitude subsonic all-weather fighter. It would be cheaper and quicker to develop, and could be a flexible and effective partner to a supersonic fighter in the defence system. The usefulness of such an aircraft would depend on how soon it is expected that long range supersonic bombers may be developed, because it would be relatively ineffective against such an aircraft.

12.0 REFERENCES

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FIG. 1

180° LEVEL TURNS FOR THREE FIGHTERS AT 50,000 FT

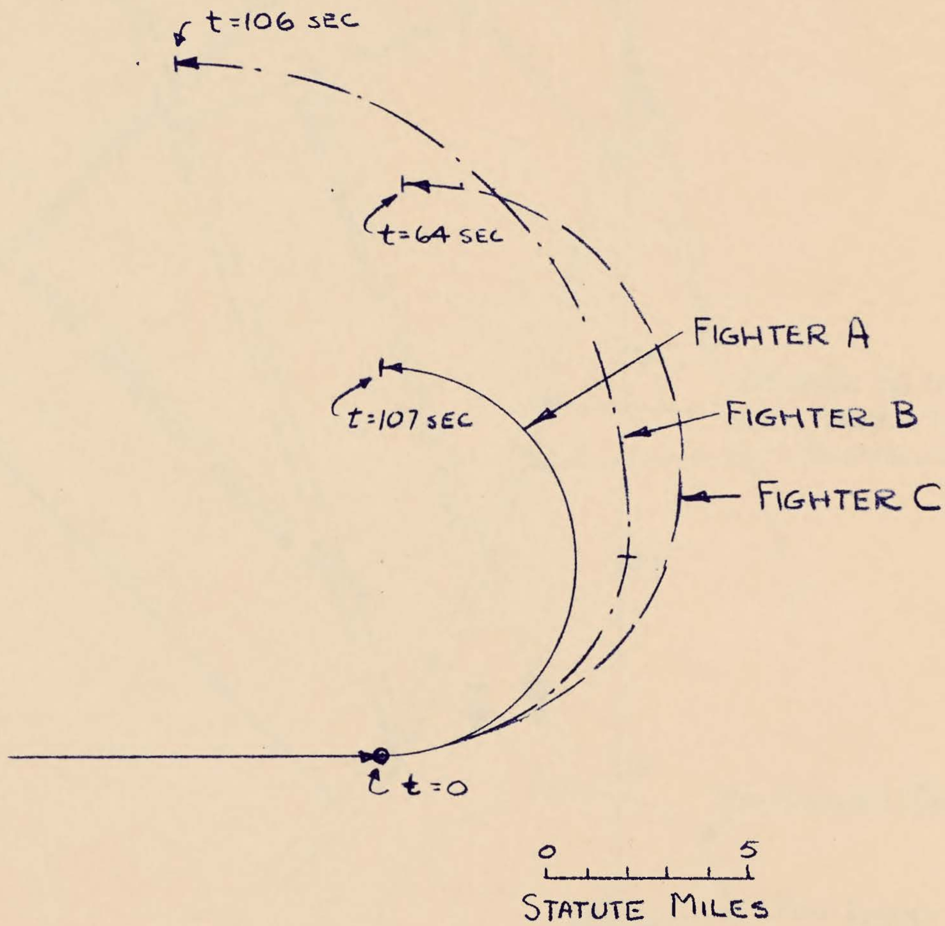

FIG. 2

APPROACH LANES FOR SUCCESSFUL ATTACK AGAINST SUBSONIC BOMBER

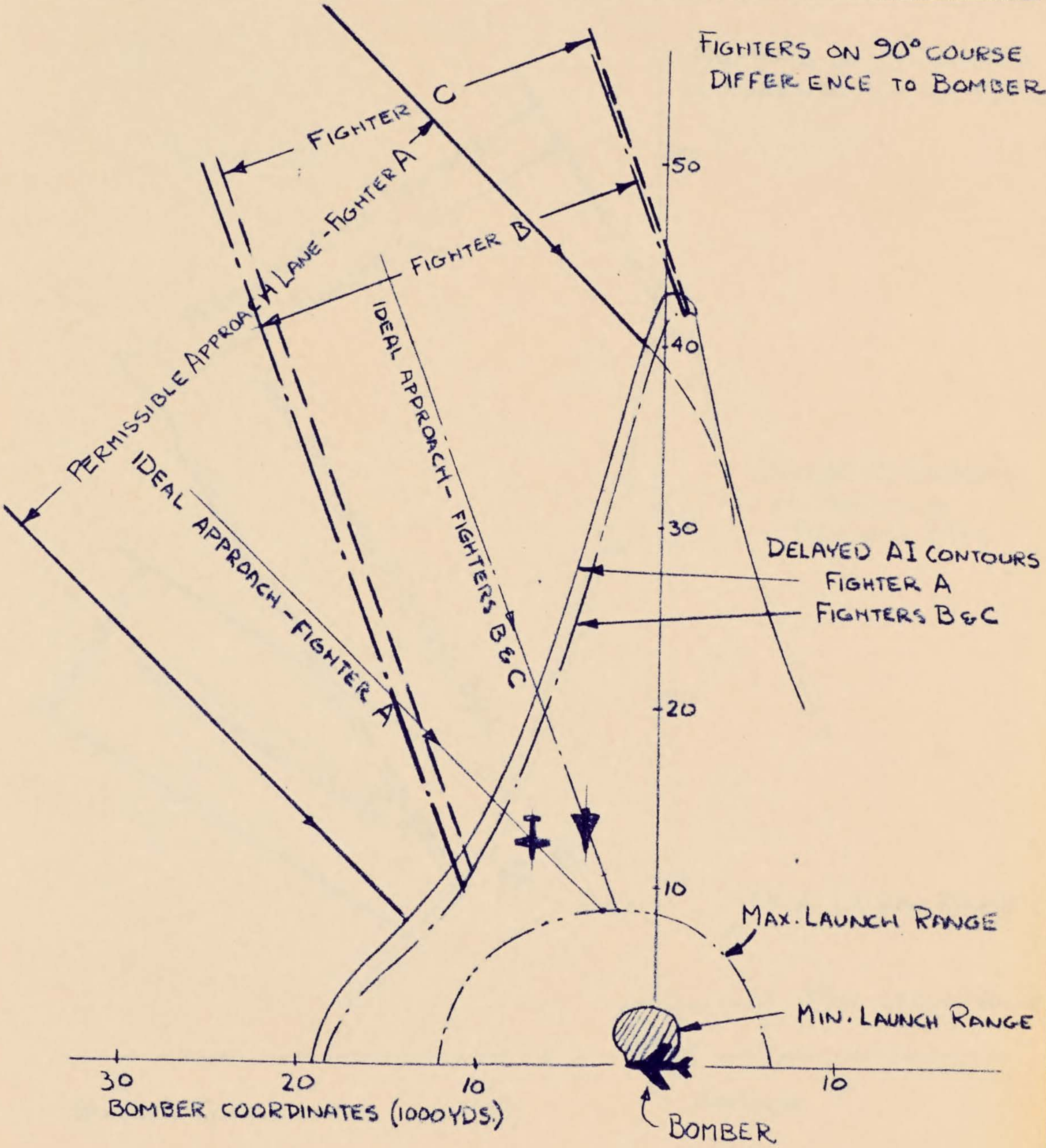

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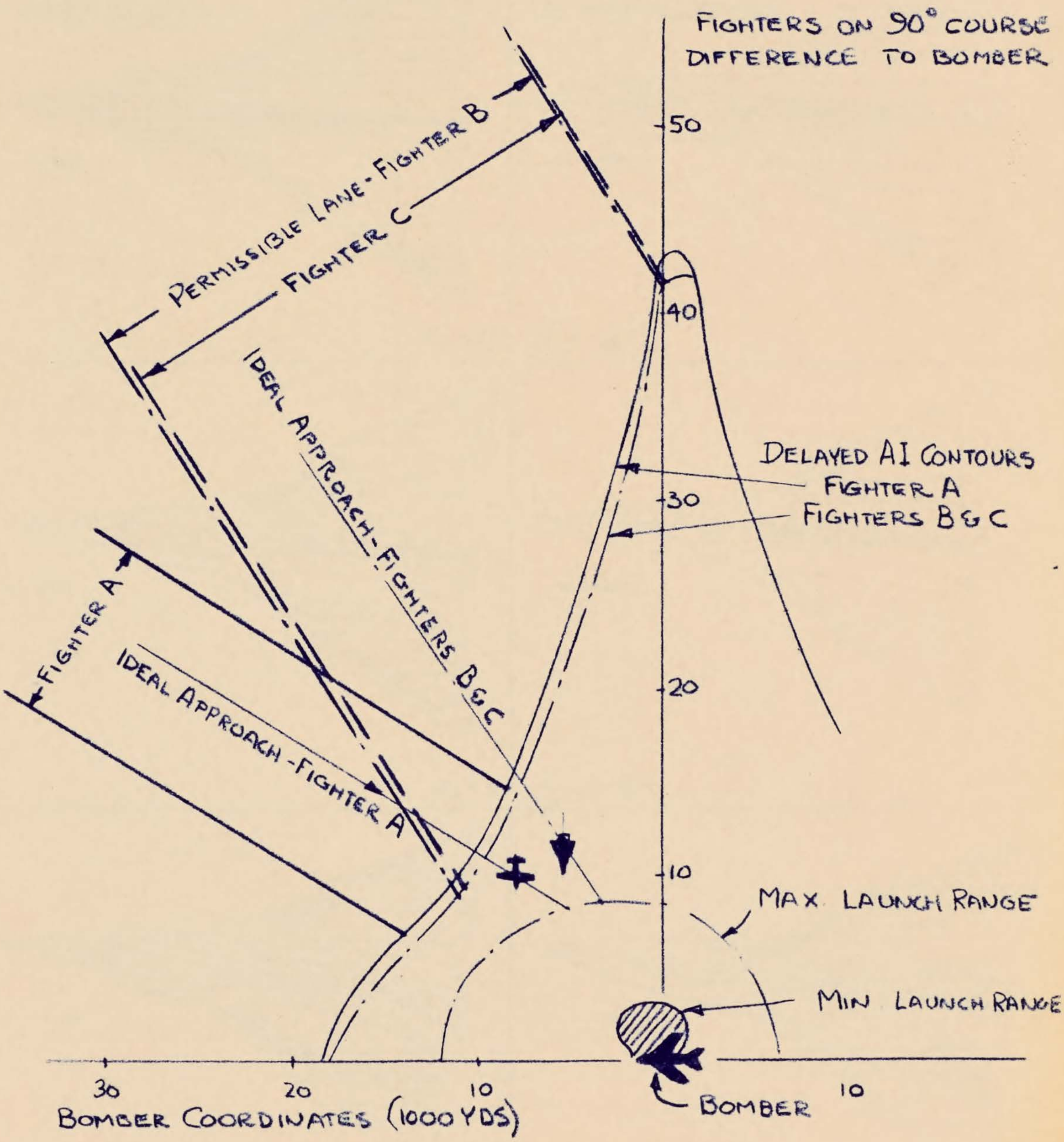
FIG. 3

APPROACH LANES FOR SUCCESSFUL ATTACK AGAINST SUPERSONIC BOMBER



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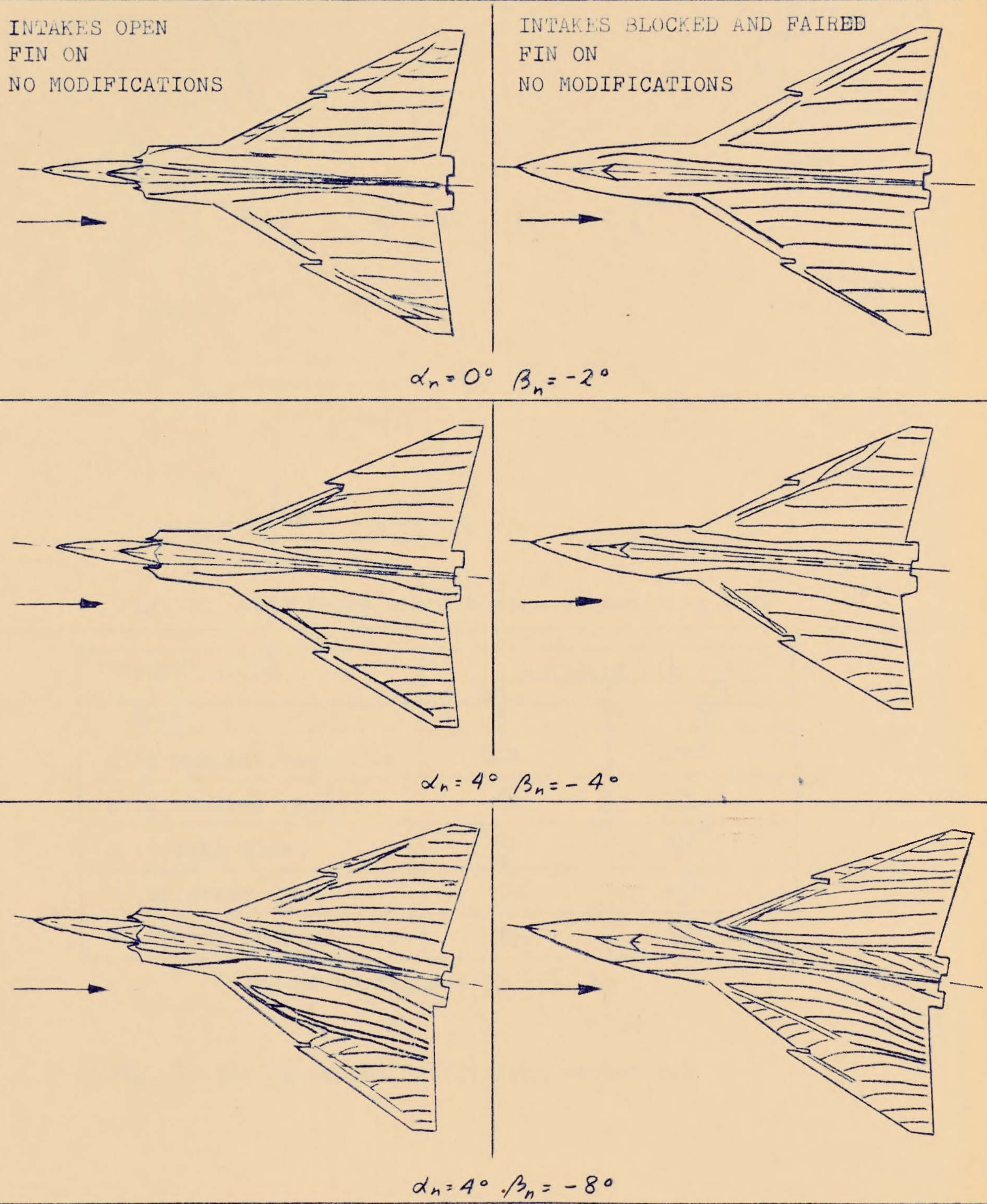
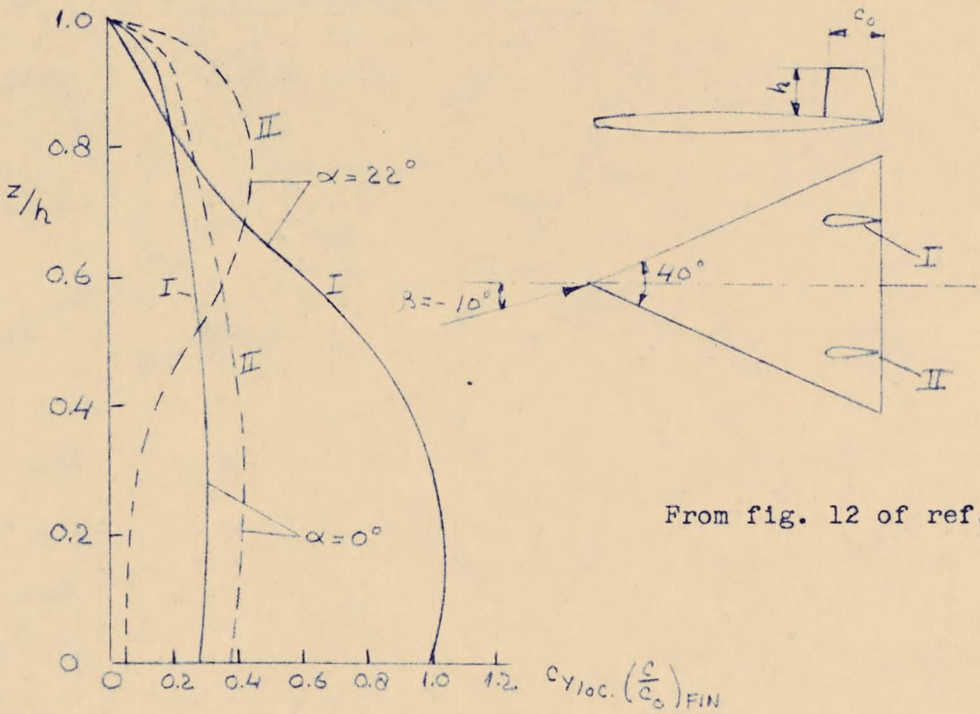


Fig. 10 Flow patterns on upper surface of wing



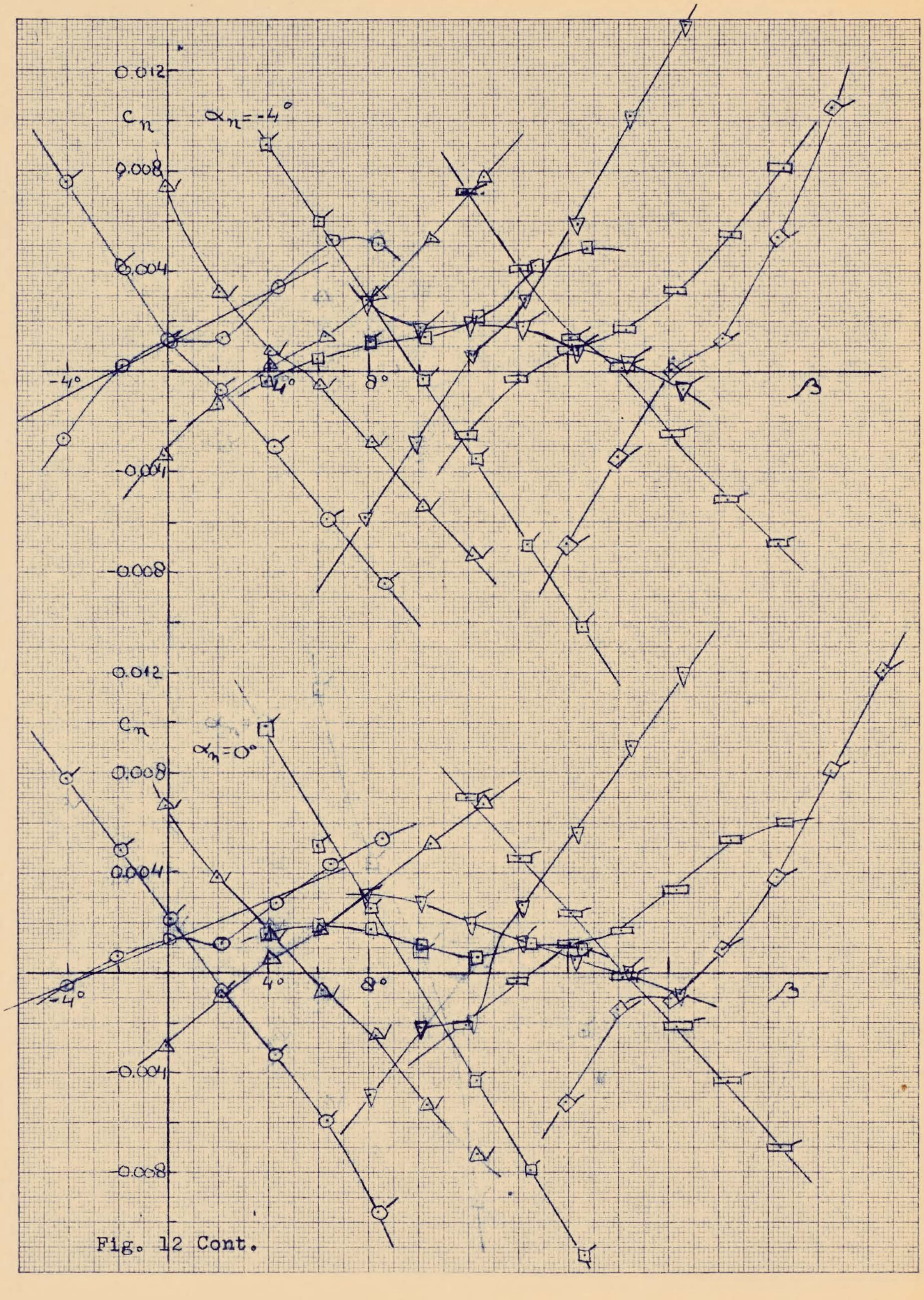
From fig. 12 of ref. 7

Fig. 11 Side force distribution on two wing fins

Modification	Standard fin	
	on	off
none	⊙	⊙/
a (1 ventral fin)	▭	▭/
b (2 ventral fins)	△	△/
c (2 wing fins)	▽	▽/
d (enlarged fin)	—	◇/
e (2 wing fences)	⊡	⊡/

Legend to figures 12, 13, 14

Fig. 12 Yawing moment coefficient versus yaw



0.012
C_n
$\alpha_n = -4°$
0.008
0.004
-4°
4°
8°
β
-0.004
-0.008
0.012
C_n
$\alpha_n = 0°$
0.008
0.004
-4°
4°
8°
β
-0.004
-0.008

Fig. 12 Cont.

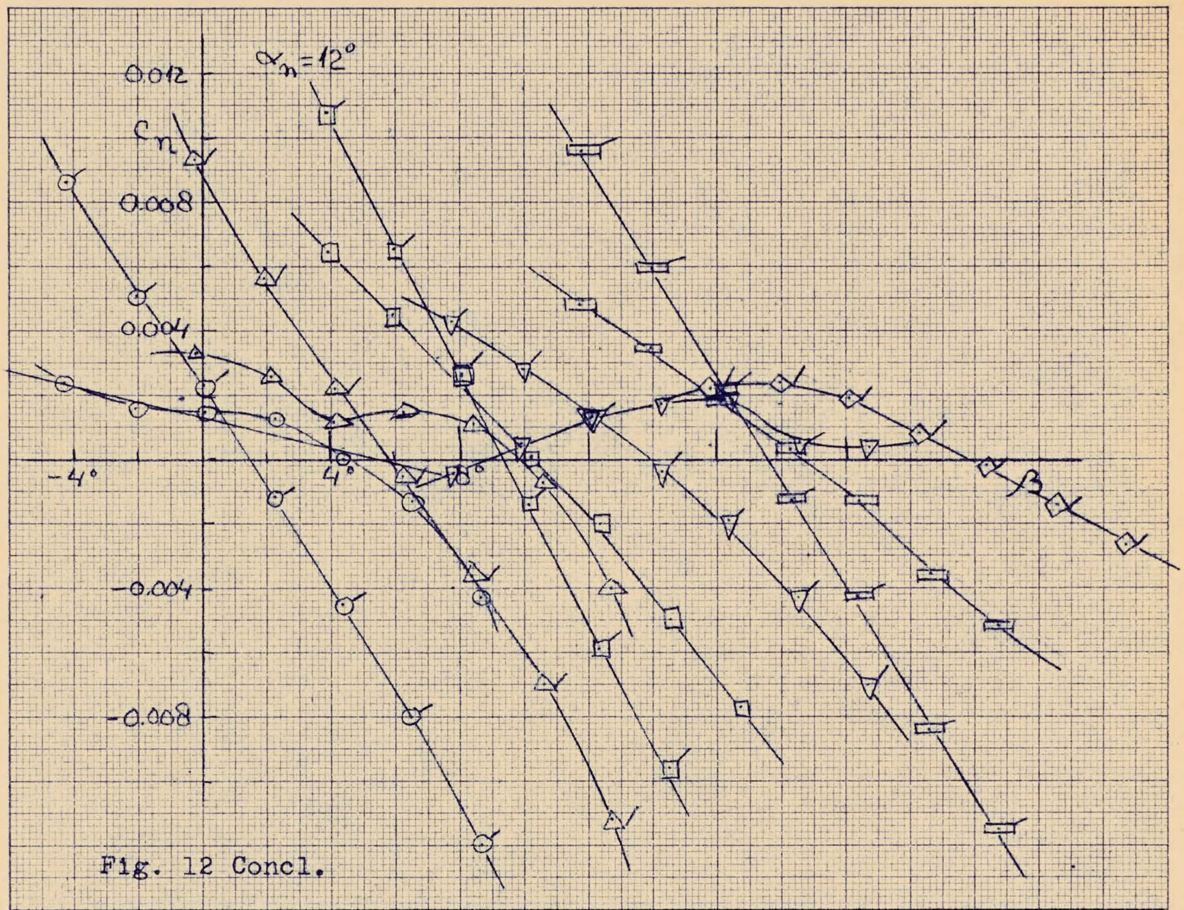
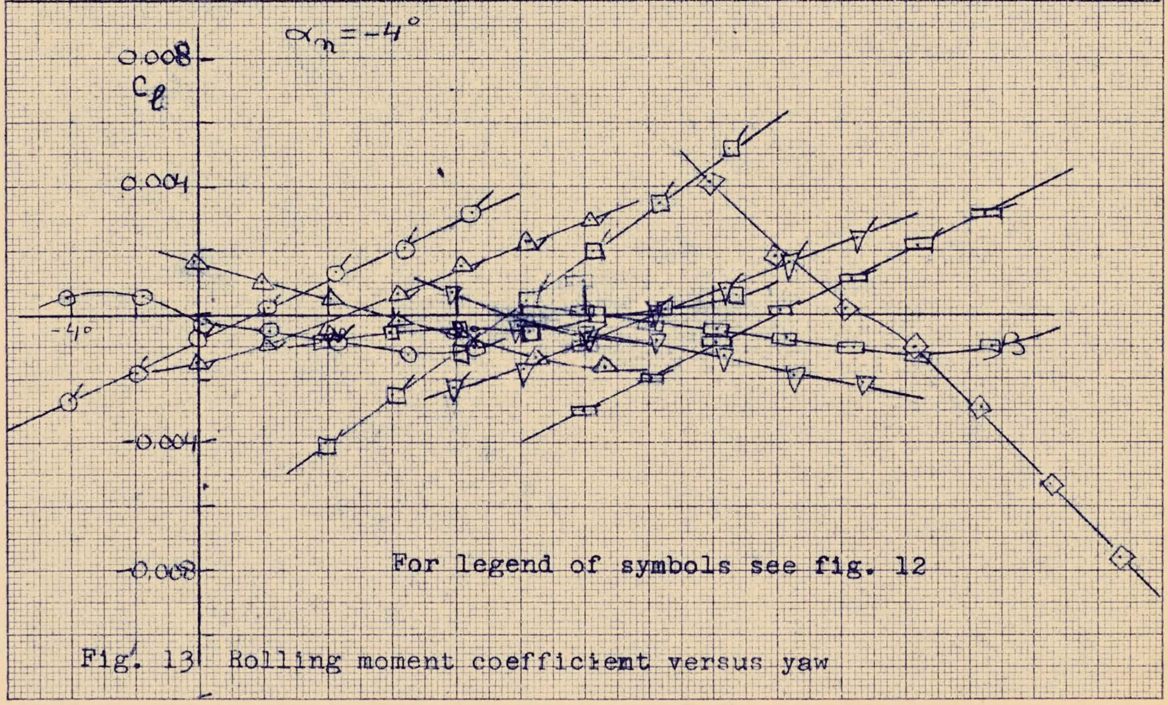
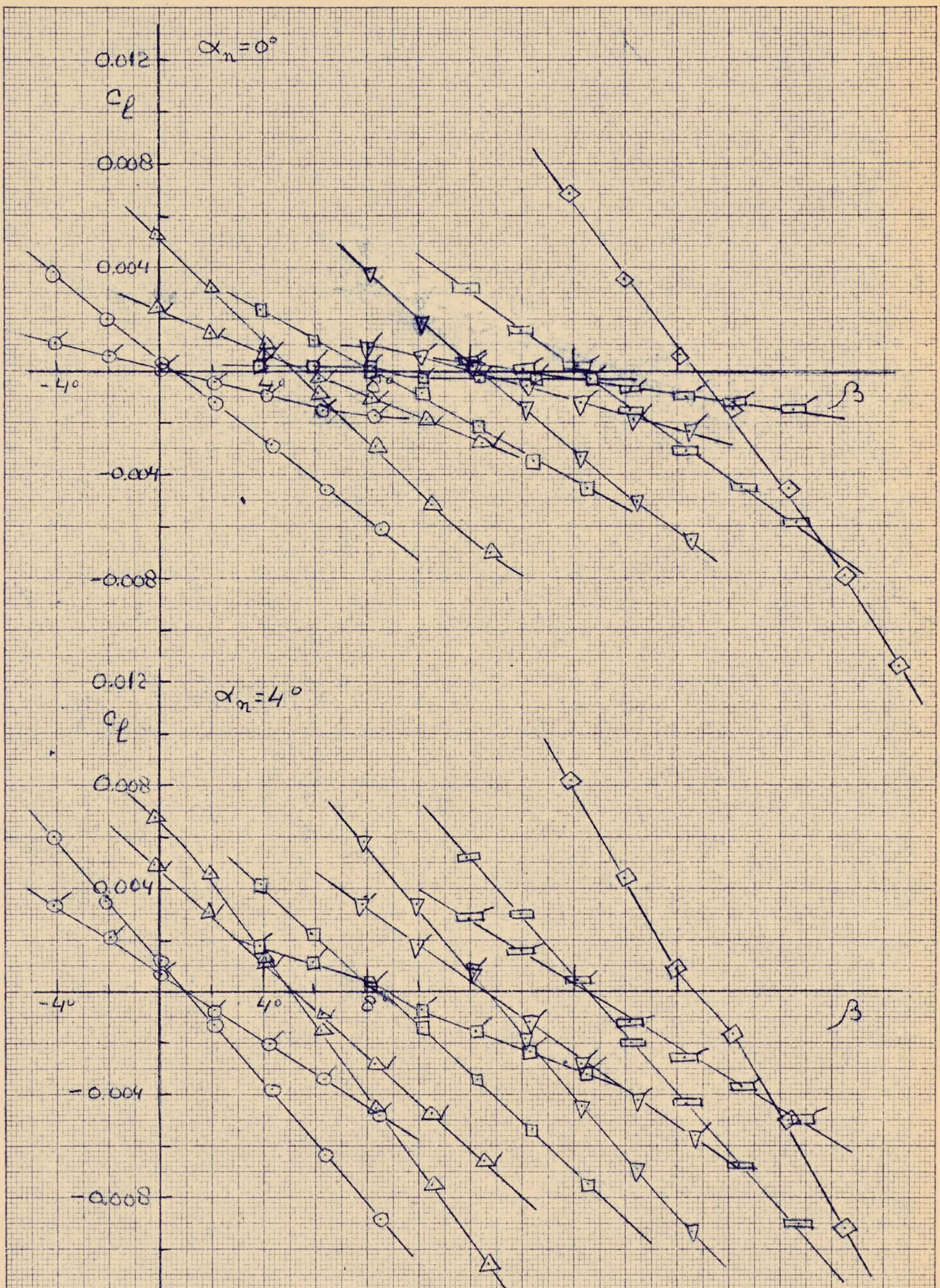


Fig. 12 Concl.



For legend of symbols see fig. 12

Fig. 13 Rolling moment coefficient versus yaw



$\alpha_n = 0°$
c_l
0.012
0.008
0.004
-0.004
-0.008
-4°
4°
8°
β
$\alpha_n = 4°$
c_l
0.012
0.008
0.004
-0.004
-0.008
-4°
4°
8°
β

Fig. 13 Cont.

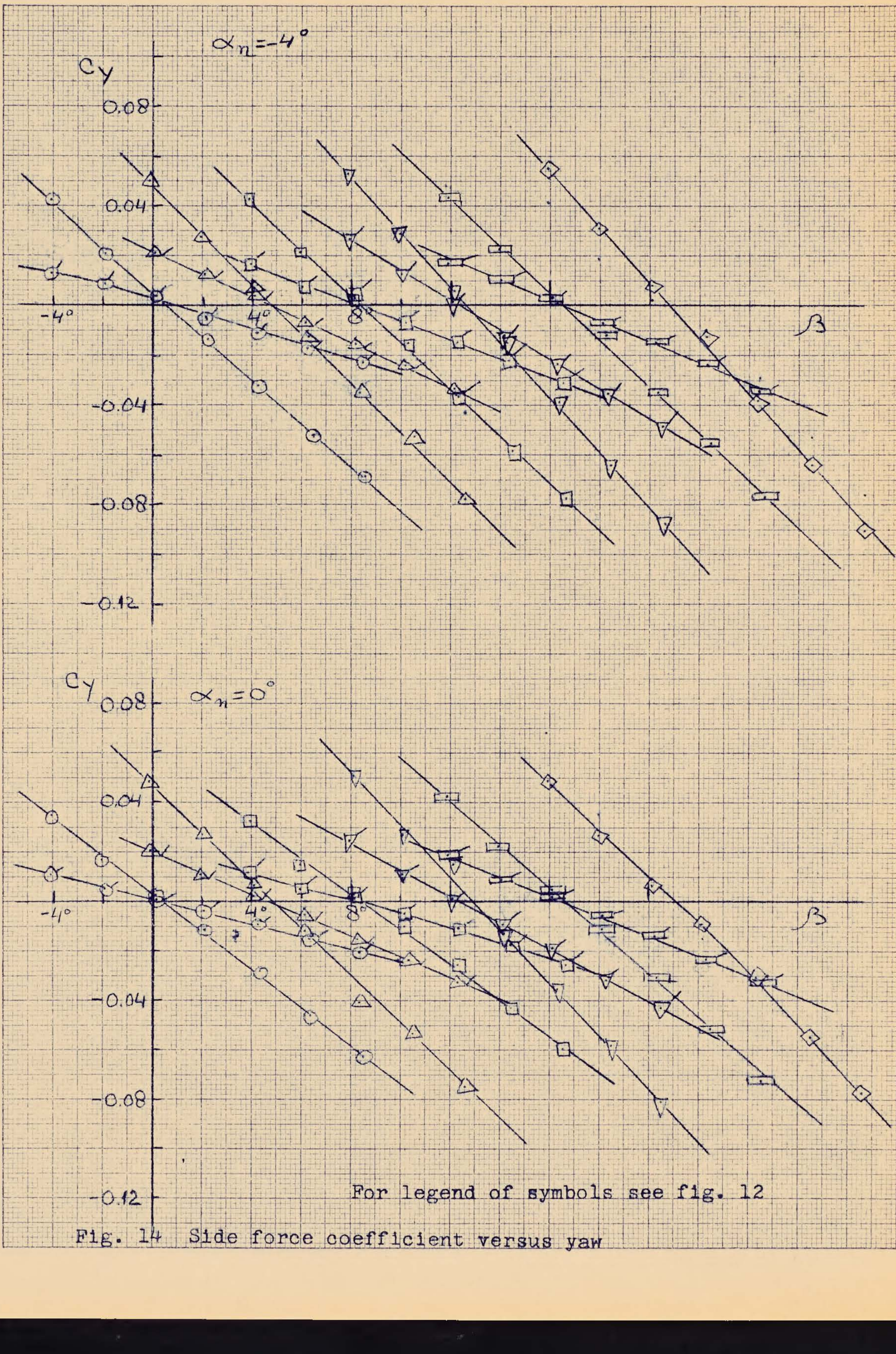


Fig. 14 Side force coefficient versus yaw

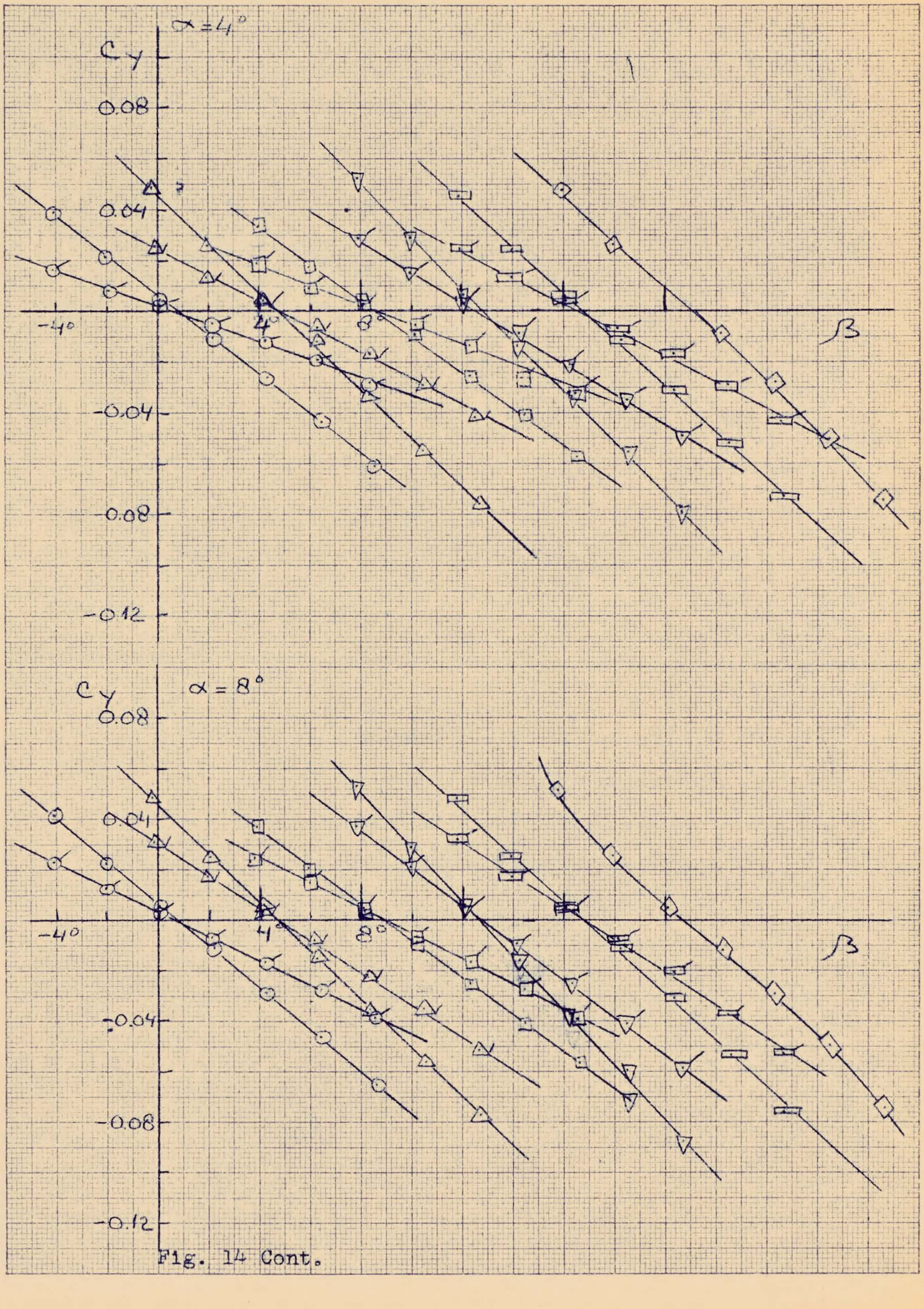


Fig. 14 Cont.

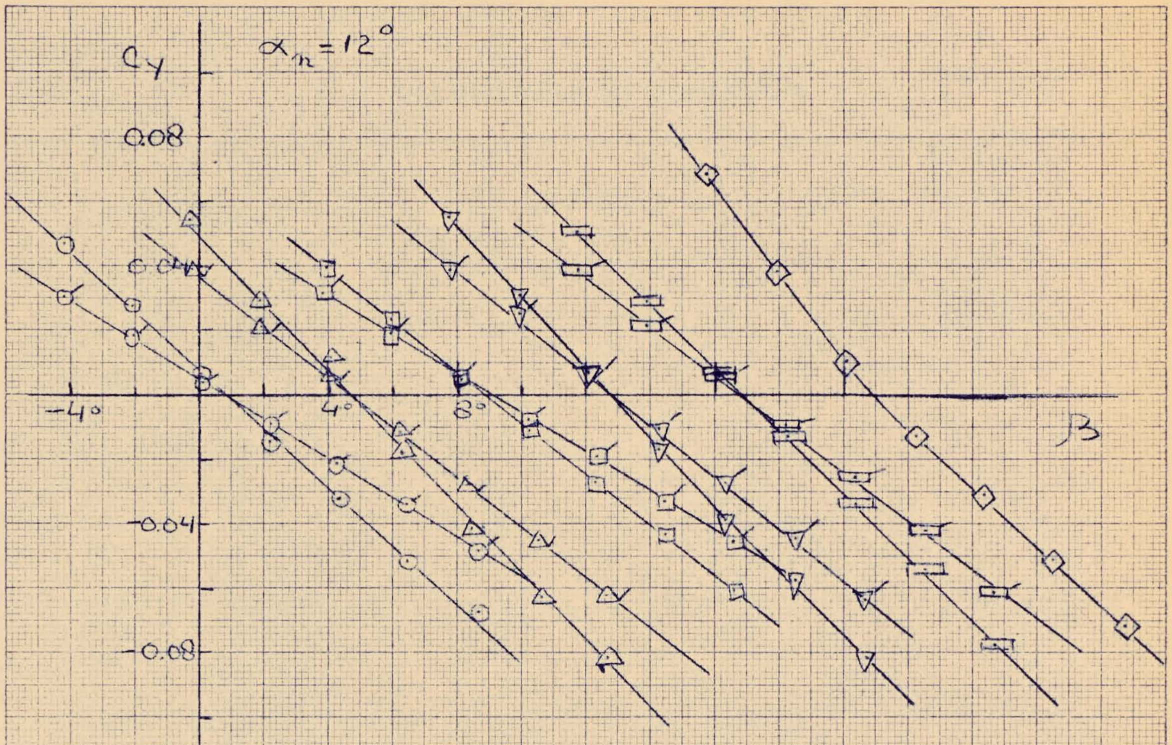


Fig. 14 Concl.

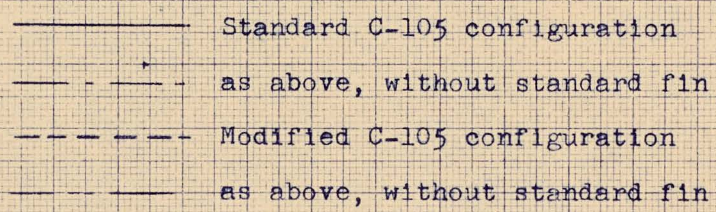
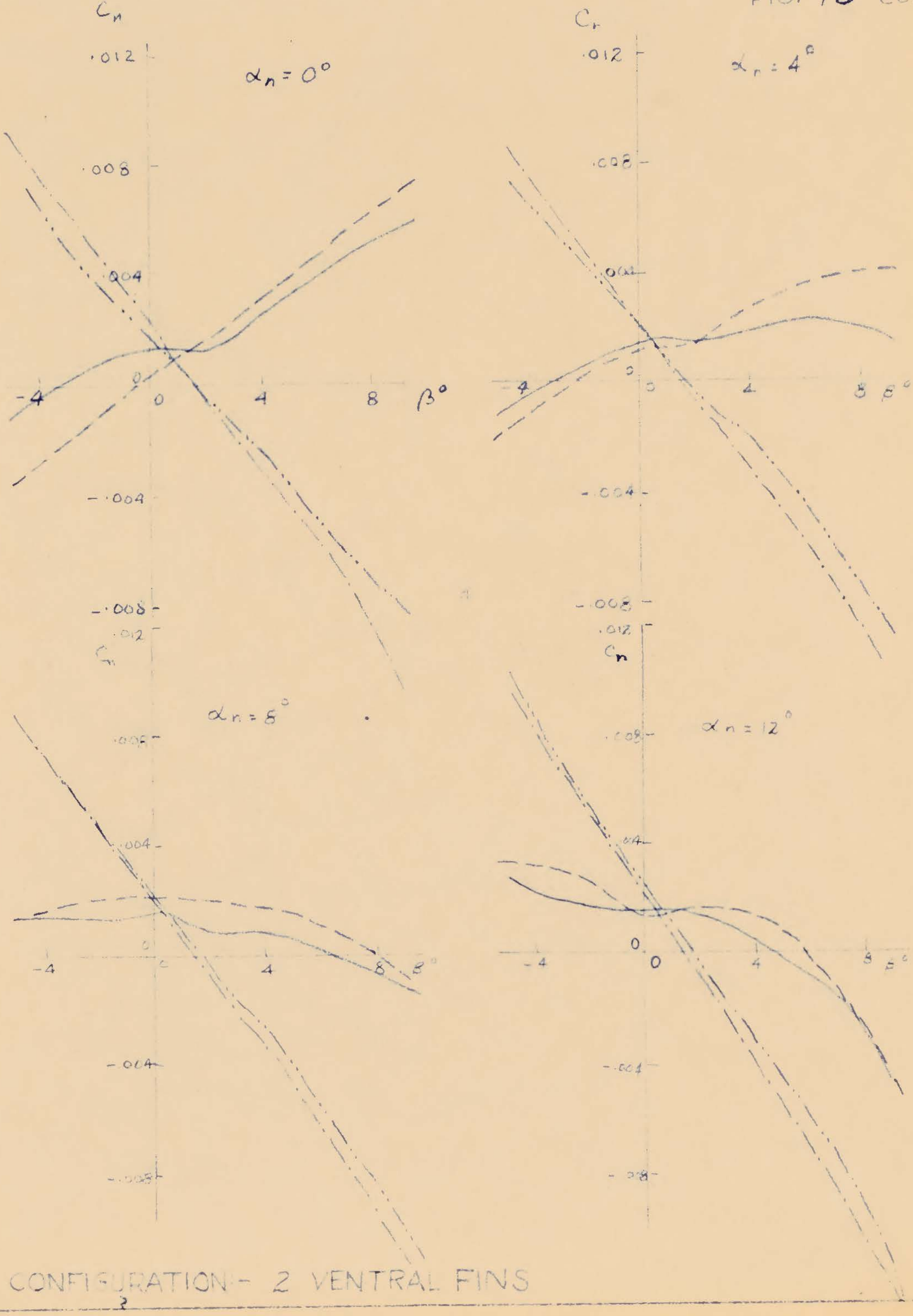


Fig. 15 Legend for figures 16, 18 and 19

NATIONAL AERONAUTICAL ESTABLISHMENT NO.

LABORATORY MEMORANDUM PAGE OF

FIG. 16 CONT.



CONFIGURATION - 2 VENTRAL FINS

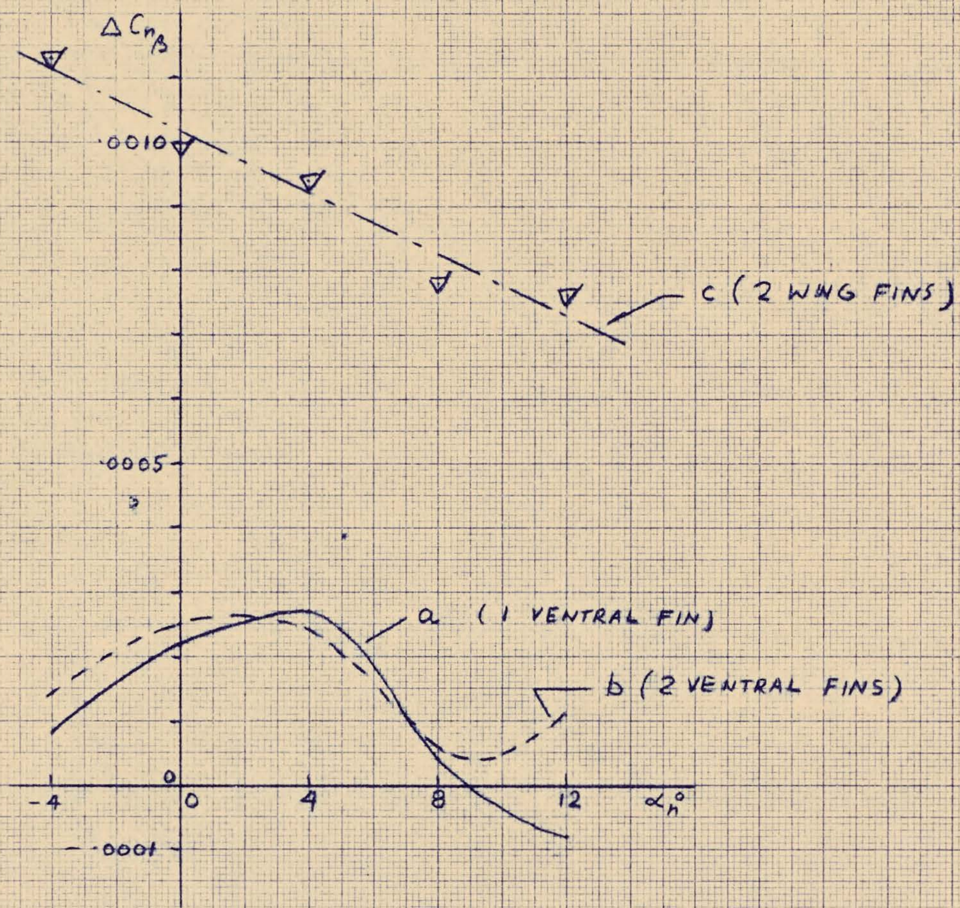
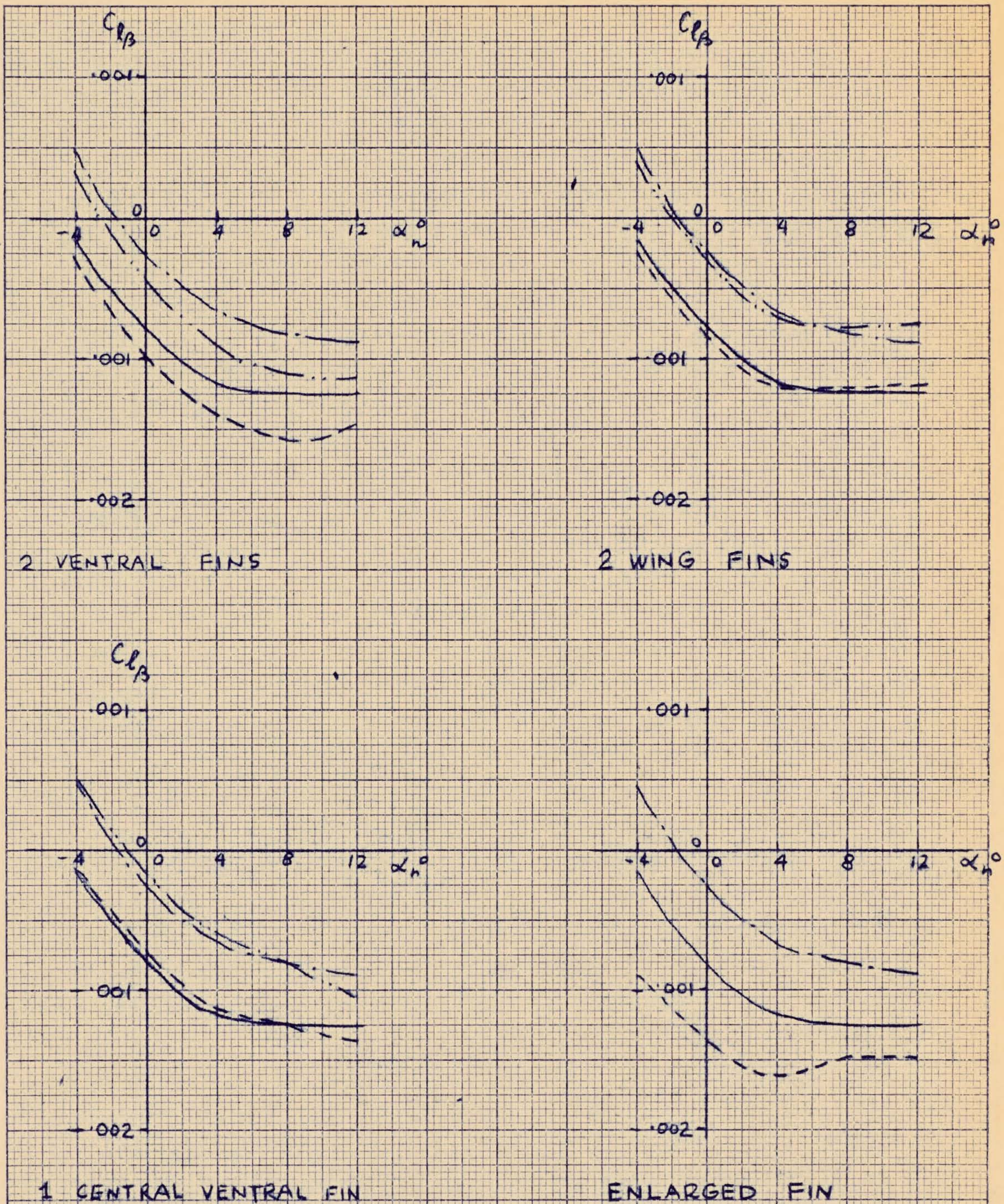
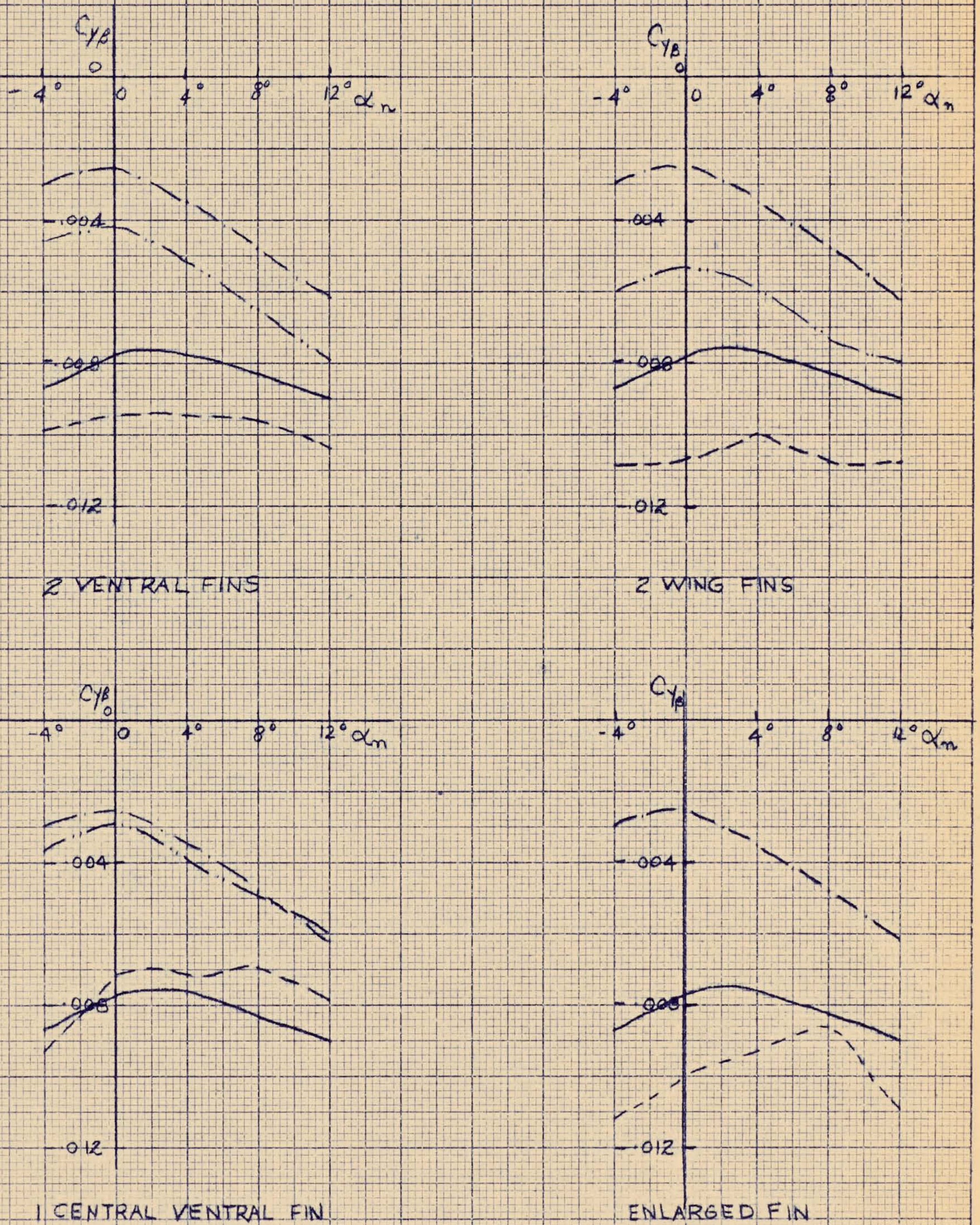


FIG. 17 CONTRIBUTIONS TO C_{n_β} OF MODIFICATIONS a, b, c (STANDARD FIN OFF CONDITIONS)



For legend see fig. 15

FIG. 18 C_{l_β} COMPARISON



For legend see fig. 15

FIG 19 $C_{Y/\beta}$ COMPARISON

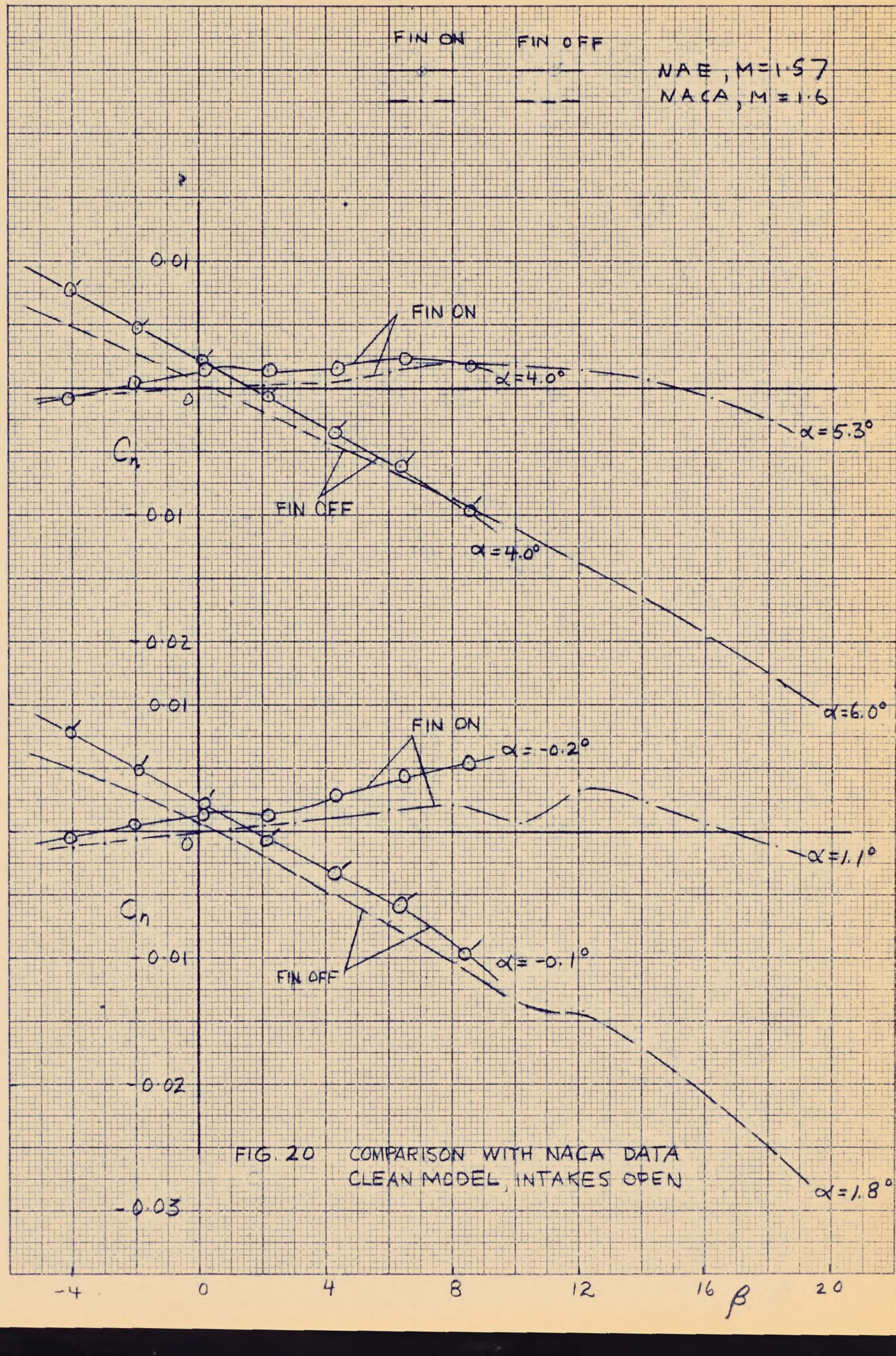


FIG. 20 COMPARISON WITH NACA DATA
CLEAN MODEL, INTAKES OPEN