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EMERGENCY MEASURES FOR INCREASING THE RANGE OF FIGHTER AIRPLANES

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SUMMARY

An analysis was made to show the relative effectiveness of streamline external fuel tanks, a fuel tank in the form of a wing mounted in a biplane position, and auxiliary wing panels attached at the wing tips to increase the span as temporary means for increasing the range of a fighter-type airplane. The airplane considered is representative of either an Army or Navy single-engine heavy fighter. Figures and charts for the various devices considered show the results of calculations of range, duration of flight, and take-off distance for both land-base and carrier operation.

The results indicated that the wing-tip extensions were the most promising of the devices considered. It was estimated that 10-foot tip extensions - that is, an increase in span of 20 feet - used in conjunction with a streamline external fuel tank would increase the range of the airplane 125 to 130 percent without any increase in the distance required to take off from either a land base or a carrier. With 5-foot tip extensions, the range would be increased 65 to 70 percent, under the same limitations. The tank wing was found to cause some reduction in the efficiency of the airplane in terms of miles per gallon. The added area would permit a greater fuel load to be carried, however, for a given take-off distance and the range would thereby be increased. For a given take-off distance from a land base, the calculated increase in range due to the tank wing was about 45 percent. The increase for a given carrier take-off would be about 30 percent. Increasing the range 50 percent by carrying extra fuel in a streamline external tank without any other modifications to the airplane would require an

increase of 20 percent in take-off distance from a land base and 32 percent from a carrier.

INTRODUCTION

The range of fighter-type airplanes is ordinarily relatively short because of high span loading and limitations on the space available for fuel. Permanent modifications in the design of the airplane to achieve longer ranges would not be acceptable because of the consequent impairment of other characteristics that are ordinarily of greater importance. Under certain circumstances, however - for example, for ferrying purposes - it would be of great value to increase the range of fighter airplanes by temporary devices, despite sacrifices in other performance characteristics.

Considerable increases in range may be obtained by carrying streamline external fuel tanks but only at the cost of a possibly prohibitive increase in take-off distance. Several methods, designed to increase the range without increasing the take-off distance, have been suggested. One of these methods consists essentially in making the external tank in the shape of an airfoil to increase the total wing area. Another method consists in adding area at the wing tips, which has the advantage of increasing not only the wing area for take-off but also the span and, thereby, the efficiency in terms of miles per gallon of fuel. Such area might be added in the form of temporary extensions attached in place of the removable fairings on the original wings.

Determination of the most expedient method will depend on a number of factors outside the field of the present investigation, such as pilot endurance, area available for take-off, and structural considerations. The following analysis is intended to provide a comparison of the suggested methods on the basis of maximum attainable range, flying time required, and take-off distances from either a land base or a carrier. The calculations were made for an airplane the characteristics of which may be considered representative of either an Army or Navy single-engine heavy fighter.

ANALYSIS

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Airplane.- The characteristics of the airplane considered in the analysis are:

Wing area, square feet	310
Wing span, feet	41
Wing incidence angle, degrees	2
Ground angle (longitudinal axis), degrees	12
Empty weight (design gross weight less normal fuel load), pounds	11,000
Engine displacement, cubic inches	2800
Supercharger	two-stage, gear-driven
Propeller	three-blade, constant-speed
Propeller gear ratio	2:1
Maximum speed at sea level, miles per hour	317
Capacity of internal fuel tank, gallons	300

A sketch of the airplane with a tank wing of 300-gallon capacity (4-ft chord by 20-ft span) is shown in figure 1. In figure 2 the airplane is shown with 10-foot wing-tip extensions (area increase, approx. 80 sq ft) and a 300-gallon streamline external tank.

Calculation of range.- The range was calculated by the Breguet formula, which takes account of the continuous reduction in power required to operate at constant lift-drag ratio. The equation is

$$R = 375 \frac{\eta}{C} \frac{L}{D} \log_e \frac{W_t}{W_e}$$

where

R range, miles

η average propulsive efficiency during flight

C average specific fuel consumption during flight, pounds per horsepower-hour

L/D lift-drag ratio of airplane

W_t weight of airplane at take-off

W_e weight of airplane with tanks empty

Calculation of aerodynamic efficiency L/D.- The values of aerodynamic efficiency L/D for use in the range equation were computed from the relation

$$\frac{L}{D} = \frac{1}{\dfrac{1.075f}{W/\rho V^2} + \dfrac{W/\rho V^2}{1.075\ \pi {b_e}^2}}$$

where

f parasite area of airplane

W weight of airplane

ρ mass density of air

V true airspeed, miles per hour

b_e effective span

For the original airplane, the value of f was calculated from consideration of the maximum speed and corresponding power output of the engine. Increments in parasite area due to the external tanks, the tank wing, and the wing-tip extensions were estimated by determining the wetted areas of these additions and multiplying by a skin-friction coefficient of 0.005, representative of a turbulent boundary layer. For the streamline external tanks, the wetted area was assumed to be that of an ellipsoid of revolution having a fineness ratio of 5 and providing the desired volume. The drag of a faired tank has been found to be slightly less than that obtained by this method.

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For the normal airplane and the airplane with wing-tip extensions, the effective span b_e was assumed to be 90 percent of the actual span. For the tank wing, the effective span was taken as the effective span of the original airplane multiplied by Munk's span factor; the value of the factor for the configuration assumed (fig. 1) was taken from reference 1; and the assumption that the lift would be distributed between the two wings in proportion to their respective areas was used.

The curves of L/D against $\frac{V}{\sqrt{W/W_e}}$, where W is the airplane weight with any fuel load and V is the true airspeed at an altitude of 10,000 feet, are plotted in figure 3(a) for the various modifications of the airplane. The curve for a given airplane configuration is independent of loading when plotted in this manner.

Calculation of engine-propeller efficiency η/C - Values of propulsive efficiency η were computed from full-scale test data on a suitable propeller-nacelle combination. Specific fuel consumption C was determined from manufacturer's performance charts for the engine considered. It was assumed that the engine was operating in low blower and subject to the limitations on engine speed and manifold pressure specified for the cruising power condition. The values of C were increased 5 percent to take account of oil consumption. The maximum value of the ratio η/C was determined for several values of brake horsepower at each of a number of airspeeds; an altitude of 10,000 feet was assumed. It was found that the maximum value of η/C at a given airspeed is practically unaffected by considerable variations in power, with the result that a single curve of η/C against true airspeed, given in figure 3(b), could be used for all the airplane modifications considered.

Determination of loading.- The weight of fuel carried was estimated on the basis of 6 pounds per gallon. This value was increased 5 percent to allow for oil consumption. The weight of the streamline external fuel tanks and the weight of the tank wing were assumed to be 15/85 of the weight of the fuel the tanks are capable of carrying. The weight of the wing-tip extensions was taken as 3 pounds per square foot of area added. The loadings used for the several modifications of the airplane that were considered in the calculations are given in the following table:

Condition	Total fuel capacity (gal)	Empty weight (lb)	Take-off weight (lb)	W_t/W_e
Normal airplane	300	11,000	12,890	1.172
300-gallon external tank added	600	11,319	15,092	1.333
5-foot wing tips added	300	11,155	13,043	1.168
5-foot wing tips and 300-gallon external tank added	600	11,474	15,247	1.328
10-foot wing tips added	300	11,300	13,188	1.166
10-foot wing tips and 300-gallon external tank added	600	11,619	15,392	1.324

<u>Calculation of take-off distance</u>.- Take-off distances from both a land base and a carrier were computed for the various airplane conditions. For the land-base take-offs, the distance required to clear a 50-foot obstacle was included. It was assumed that flaps would not be used and that there was no wind. The ground-run distances were computed by the method of reference 2. The take-off speed was taken as 5 percent in excess of the power-off stalling speed and the rolling-friction coefficient, as 0.05. Air-run distances were estimated from the results of step-by-step integrations of the air-run flight path, based on the assumption that the lift coefficient at which the airplane takes off would be maintained up to the 50-foot height. For the carrier take-offs, only the distance required to attain take-off speed was calculated. Estimation of take-off speed was based on the assumption that the tail wheel would be in contact with the deck at take-off. The airplane was assumed to be equipped with partial-span slotted flaps that would be deflected 30° for carrier take-offs. The deck-wind velocity was taken as 25 knots and the rolling-friction coefficient, as 0.02. The method of refer-

ence 2 was used for the calculation of the take-off distances.

For both land-base and carrier take-offs, account was taken, as well as possible, of the effects of slipstream and proximity of the ground. Lift increments due to the slipstream were estimated from the semiempirical formulas given in reference 3. The parasite drag of parts of the airplane in the slipstream was assumed to be increased in proportion to the increase in dynamic pressure in the slipstream. It was assumed that the induced drag associated with the lift increment due to the slipstream would be the same as though this lift increment were obtained with a flap having a span equal to the slipstream diameter. The effects of ground interference on the lift-curve slope and induced drag were estimated on the basis of Wieselsberger's adaptation of biplane theory (reference 4).

RESULTS AND DISCUSSION

Chart for range and take-off distance.- A chart, from which the range, mean speed or duration of flight, and take-off distances from a land base or a carrier may be estimated for any of the cases considered, has been constructed from the results of the calculations of range and take-off distance and is given in figure 4. Values of the range efficiency factor $\frac{\eta}{C}\frac{L}{D}$ are plotted in the upper left-hand section of the chart against a variable speed scale just below. This plot shows lines of constant mean speed sloping to the left with increasing values of the ratio of take-off weight to empty weight, given on the diagonal scale to the right, and thereby takes account of the fact that the speed corresponding to a given point on the $\frac{\eta}{C}\frac{L}{D}$ curve for a given condition increases with increasing weight. Inasmuch as the value of η/C (fig. 3) for a given speed is found to be practically independent of loading for the engine-operating conditions assumed, the value corresponding to a given value of L/D will vary somewhat with loading. The variation, however, is small and values of η/C for the airspeed corresponding to the average of the full and empty loading for each airplane condition were therefore used in determining the $\frac{\eta}{C}\frac{L}{D}$ curves.

In the upper right-hand section of the chart, curves defining the relation between $\frac{\eta}{C}\frac{L}{D}$ and W_t/W_e for constant values of range are plotted. The lower part of the chart shows the variation with W_t/W_e of take-off distance from a land base or a carrier for the various airplane configurations.

The method of using the chart is indicated in figure 4 by the dashed lines drawn between the small circles on the curves and scales. The case illustrated is that of estimating the maximum range and duration of flight of the normal airplane for which the take-off distance from a land base is limited to 2500 feet. A line is drawn vertically from the 2500-foot point on the land-base take-off curve for the normal airplane through the W_t/W_e scale and up to the range section. Another line is drawn horizontally from the peak of the proper $\frac{\eta}{C}\frac{L}{D}$ curve to intersect the vertical line. (It will be noted that the value of $\frac{\eta}{C}\frac{L}{D}$ is between the peaks of the no-external-tank and the 300-gallon-external-tank curves to take account of the fact that an intermediate external-tank size is required for the case assumed in the example.) The intersection of the horizontal and vertical lines gives the value of maximum range - about 2050 miles for the example. In order to estimate the mean velocity, a vertical line is drawn down from the point corresponding to the value of $\frac{\eta}{C}\frac{L}{D}$ used in determining the range. The point of intersection of this line with a horizontal line drawn from the previously established point on the W_t/W_e scale gives the mean speed of the flight - about 206 miles per hour for the example. The duration of the flight is given by dividing the range by the mean speed and is found to be about 9.95 hours. The same procedure would be followed for the case of take-off from a carrier, using the carrier take-off curves instead of the land-base curves.

Figures 5 and 6 have been prepared from the chart in figure 4 to provide a more direct comparison of the various means for increasing the range. Figure 5 shows the minimum take-off distances and the corresponding duration of flight plotted against range. Figure 6 gives the variation of take-off distances with range when the duration of flight for a given range is the same for all cases as that for the original airplane operating at maximum efficiency.

Streamline external tank.- In figure 5 it is shown that, by increasing the fuel capacity of the airplane from 300 to 600 gallons through the use of a streamline external tank, the maximum range would be increased from about 1450 to 2600 miles or about 80 percent. The take-off distance from a land base would be increased from 2160 feet to 2940 feet or about 35 percent. From a carrier, the take-off distance would be increased from 308 to 500 feet or about 62 percent. The extent to which an increase in take-off distance from a land base would be acceptable depends, of course, on the size of airfield available. For carrier operation, however, any material increase in take-off distance would probably be a serious disadvantage.

Tank wing.- The tank wing is essentially a temporary means of providing added wing area in order that the airplane may take off with a greater fuel load for certain long-range missions and, at the same time, provides tank space for this extra fuel. This auxiliary wing would probably be mounted as the upper wing of a biplane as shown in figure 1. With such an arrangement, it would be theoretically possible to increase the effective span of the airplane to some extent but the high aspect ratio that would be required for the auxiliary wing would probably unduly complicate the structural problems. For the purposes of this analysis, it was assumed that a tank wing of aspect ratio 5 with an area of 80 square feet and a fuel capacity of 300 gallons would represent a reasonably practicable case. This arrangement entails a reduction in the effective span of the combination of about 2 percent in comparison with the original airplane. The wetted area and hence the parasite-drag increase due to the tank wing, furthermore, is about twice that of a body of revolution of equal volume. As a result, the airplane with the tank wing is somewhat less efficient than the airplane with a streamline external tank. (See figs. 3 and 4.)

The effect of this reduced efficiency shows in figure 5 as a reduction in range from 2600 to 2440 miles with a 600-gallon fuel load. The tank wing does, however, give an increase in range for a given take-off distance, because of the greater fuel load that can be carried. For land-base operation, the tank wing increases the range from 1440 to 2100 miles or about 45 percent for the same take-off distance as for the original airplane with the normal full fuel load of 300 gallons. For carrier operation, the range would be increased to 1750 miles or about 20 percent. The effectiveness of the tank wing for carrier operation in comparison with that for land-base operation is reduced because the flap on the original wing is used for the carrier take-offs and the added wing area due to the tank wing does not, in this case, proportionately increase the take-off lift.

Wing-tip extensions.- Increasing the span of an airplane, other things remaining equal, will proportionately increase the maximum range attainable with a given fuel load. This fact suggests the use of auxiliary panels, attached to the wing tips in place of the removable tip fairings (see fig. 2), as a promising means for increasing the range.

Inasmuch as the greatest range is attained at moderate speeds, it is possible that these temporary tip extensions could be constructed of fairly light wood or plastic. Furthermore, because the wing of a fighter airplane is designed for loadings much greater than those encountered in level flight, major changes in the main wing structure might not be necessary. It is suggested that, by using a greater taper in the tip extensions as shown in figure 2 and at the same time suitably increasing the camber of the airfoil sections, the gust loads imposed on the main wing structure by the tip extensions can be considerably reduced without materially affecting the range or the take-off distance.

The tip extensions would considerably reduce the lateral maneuverability of the airplane. For the airplane considered, it is estimated that tip extensions of 10-foot span (over-all span increased from 41 to 61 ft) would decrease the maximum value of the tip helix angle $pb/2V$ attainable with the ailerons about 30 percent. It is believed that this loss in control effectiveness would not be too serious for the maneuvers which might be required in a long-range flight. Flight tests have shown that the moment of inertia of an airplane about its longitudinal axis can be at least doubled without materially affecting lateral maneuverability; accordingly, the added moment of inertia due to the tip extensions should have no noticeable effect on the response to aileron control.

The relatively low stability that is normally characteristic of fighter-type airplanes would tend to increase pilot fatigue on a long-range flight. The temporary devices used for increasing the range should therefore be designed, insofar as possible, to improve the stability, Increased longitudinal stability could be obtained by providing sweepback in the wing-tip extensions or by properly disposing the fuel load carried in external tanks. Wing-tip extensions might be designed with sufficient dihedral angle to improve spiral stability, if necessary, in order that the pilot could fly with rudder alone in smooth air.

The use of wing-tip extensions, either alone or in conjunction with streamline external fuel tanks, appears to be the most effective of the means considered for increasing the range attainable with fighter airplanes. Not only is the efficiency of the airplane increased, as shown in figures 3 and 4, with the result that the range with a given fuel load is greater, but also the added wing area will give a substantial improvement in take-off distance. In figure 5, the maximum range of the airplane with 600 gallons of fuel is shown to be increased from 2600 to 3030 miles with 5-foot tip extensions and to 3450 miles with 10-foot tip extensions. It is also shown that, without exceeding take-off distance of the original airplane from either a land base or a carrier, the range is increased from 1440 to about 2400 miles or almost 70 percent with 5-foot tip extensions and to about 3300 miles or between 125 and 130 percent with 10-foot tip extensions. The wing-tip extensions, in contrast with the tank wing, appear equally effective in increasing the range for a given take-off distance from either a land base or a carrier because the increased lift-curve slope with the wing-tip extensions gives a relatively higher take-off lift for the fixed angle of attack of the carrier take-offs than is obtained with the tank wing.

Inasmuch as an increase in span reduces the airspeed at which maximum efficiency is attained, the time of flight over a given distance will be greater with the wing-tip extensions than with the original airplane or with the tank wing, if the primary consideration is the attainment of a given range with the least possible fuel load or take-off distance. This case is represented in figure 5. When the distance to be flown is so great as to tax the pilot's endurance, it may be desirable to fly at speeds higher than those at which maximum efficiency occurs, even though a greater fuel load and take-off distance will be required. Comparison of figures 5 and 6 shows that the flying speed for the airplane equipped with wing-tip extensions could be increased to the extent that the duration of flight for a given range is the same as for the original airplane without seriously increasing the take-off distances for a given range or, conversely, without greatly reducing the range attainable for a given take-off distance.

CONCLUDING REMARKS

Of the methods considered for temporarily increasing the range of fighter-type airplanes, the use of auxiliary wing-tip extensions appears the most promising. For the airplane considered, it was estimated that 10-foot extensions - that is, an increase in span of 20 feet - used in conjunction with an external fuel tank would increase the range of the airplane 125 to 130 percent without any increase in the distances required to take off from either a land base or a carrier. With 5-foot tip extensions, the range would be increased 65 to 70 percent, under the same limitations.

An auxiliary wing of 4-foot chord and 20-foot span mounted above the main wing and providing tank capacity for 300 gallons of extra fuel, was shown to give somewhat lower efficiency in terms of miles per gallon than the original airplane with the extra fuel carried in a streamline external tank. The tank wing would permit a greater fuel load to be carried for a given take-off distance because of the added wing area, and the range would thereby be increased. For a given take-off distance from a land base, the increase in range was estimated to be about 45 percent. The increase for a given carrier take-off would be about 20 percent.

Increasing the range 50 percent by carrying extra fuel in streamline external tanks without any other modifications to the airplane would entail an increase of 20 percent in take-off distance from a land base and 32 percent from a carrier.

Selection of the most suitable method for a particular application will of course depend on other factors besides the attainable range and take-off performance, such as structural problems, pilot endurance, and area available for take-off. For example, if in a given case the duration of flight with external tanks alone is equal to the endurance of the pilot and if the area and the span available for take-off are adequate, there will be little advantage in the use of more efficient methods.

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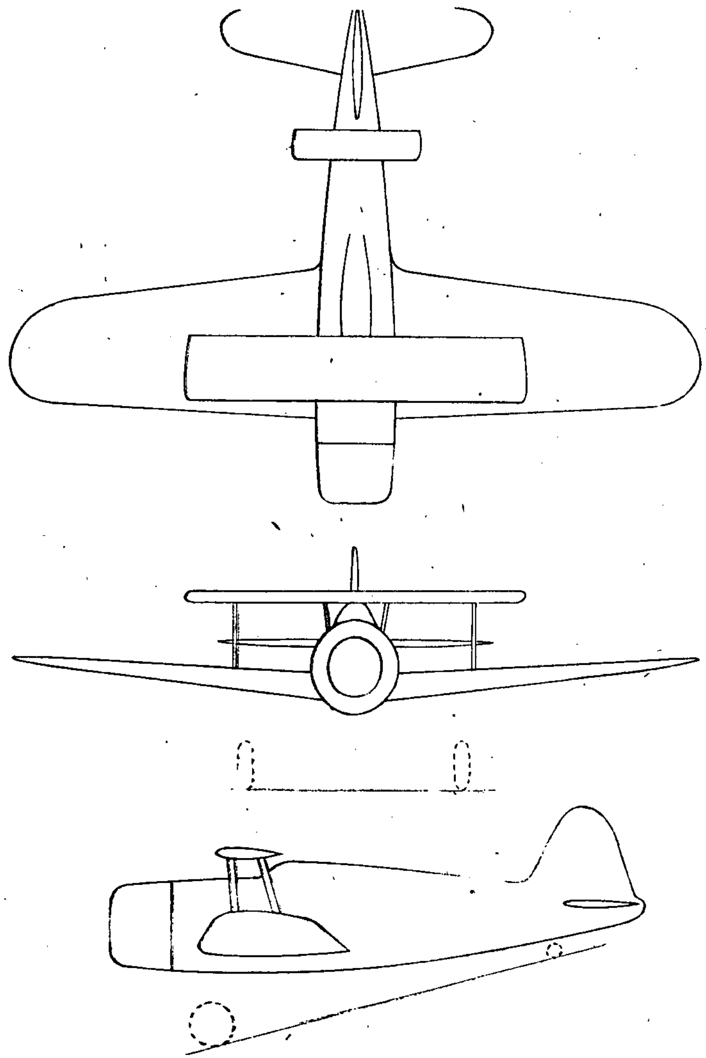

Figure 1.- Fighter airplane with 300-gallon tank wing.

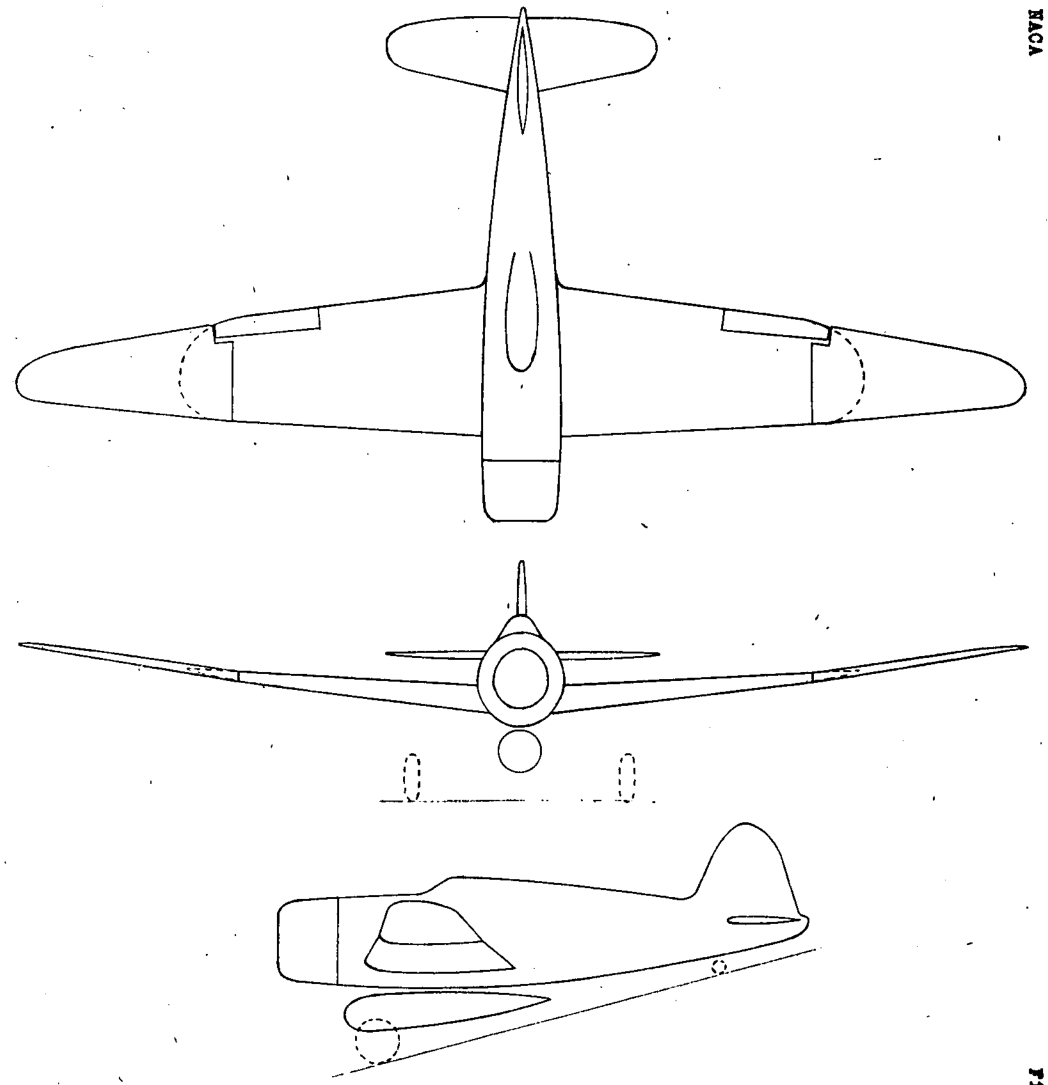

Figure 2.-
Fighter airplane with 10-foot wing-tip extensions and 300-gallon external fuel tank.

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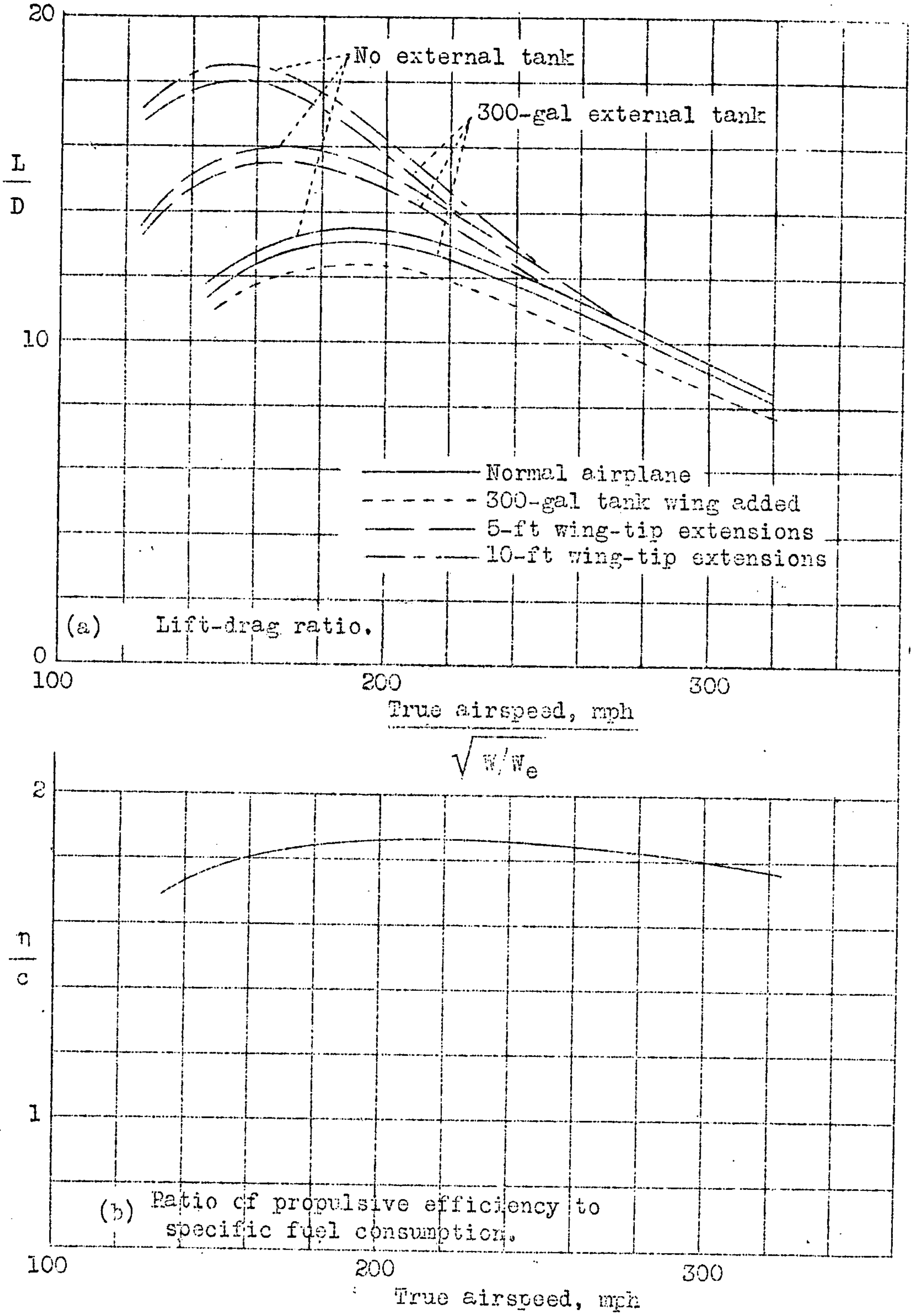

Figure 3.- Variation with true airspeed of lift-drag ratio and ratio of propulsive efficiency to specific fuel consumption for various modifications of fighter airplane. Altitude = 10,000 feet.

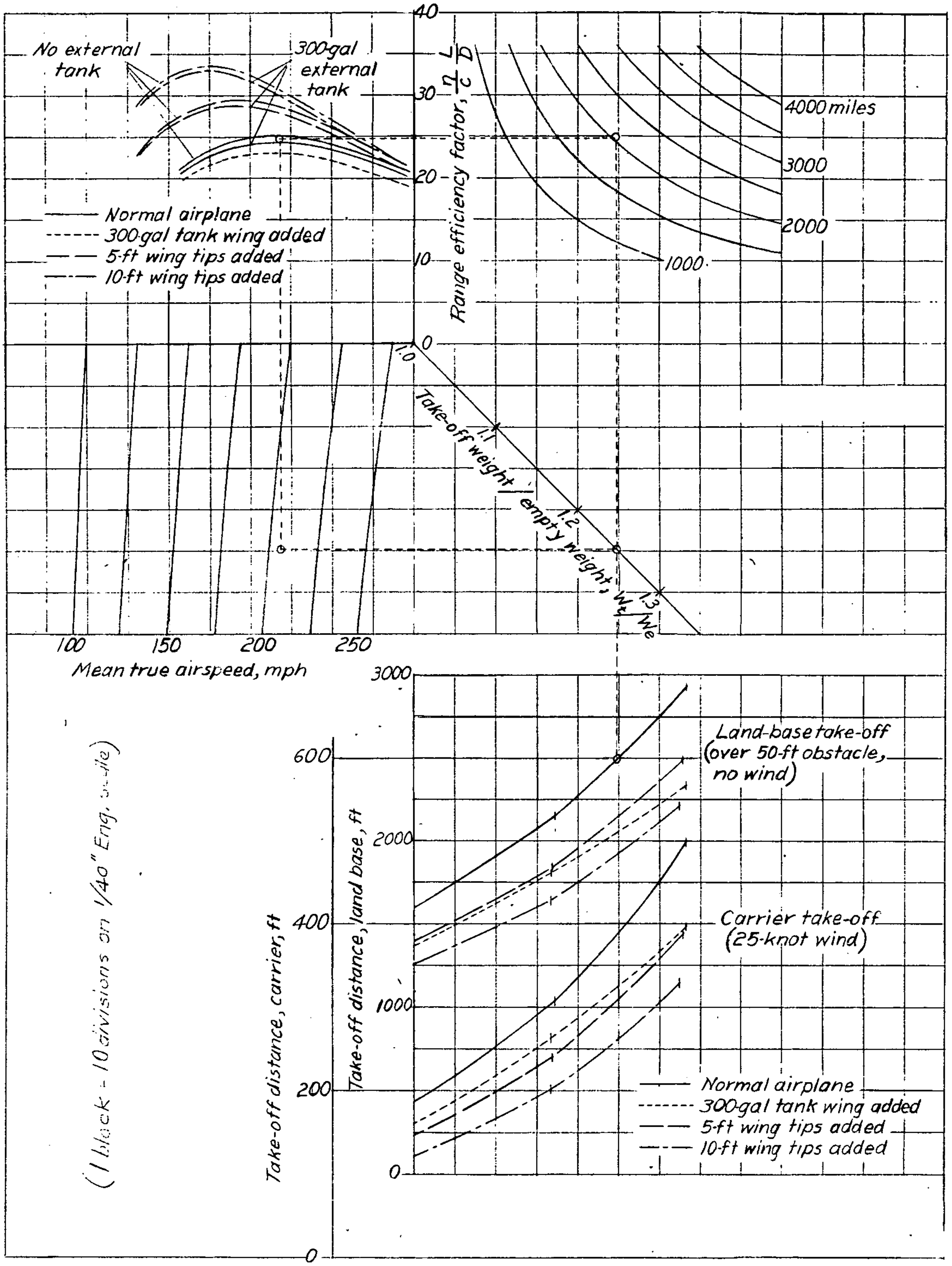

Figure 4.- Chart for estimating range, duration of flight, and take-off distance for various modifications of fighter airplane. Altitude = 10,000 feet. Vertical marks on take-off curves denote 300- and 600-gallon fuel load.

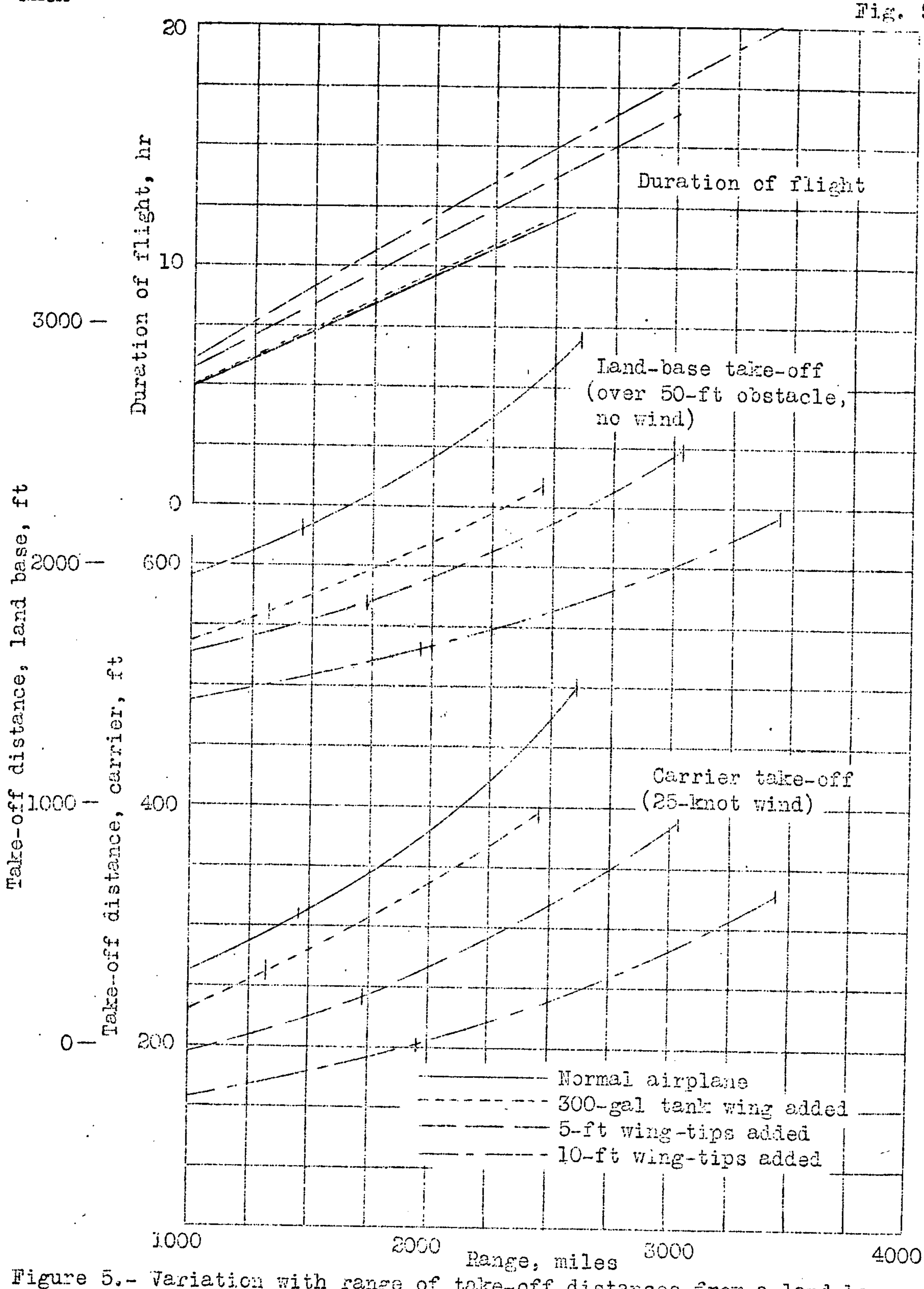

Figure 5.- Variation with range of take-off distances from a land base and a carrier and duration of flight for various modifications of fighter airplane. Flight at 10,000 feet at speed of maximum η/C L/D for each condition. Vertical marks on curves of take-off distance against range denote take-off distance and range with 300- and 600-gallon fuel loads.

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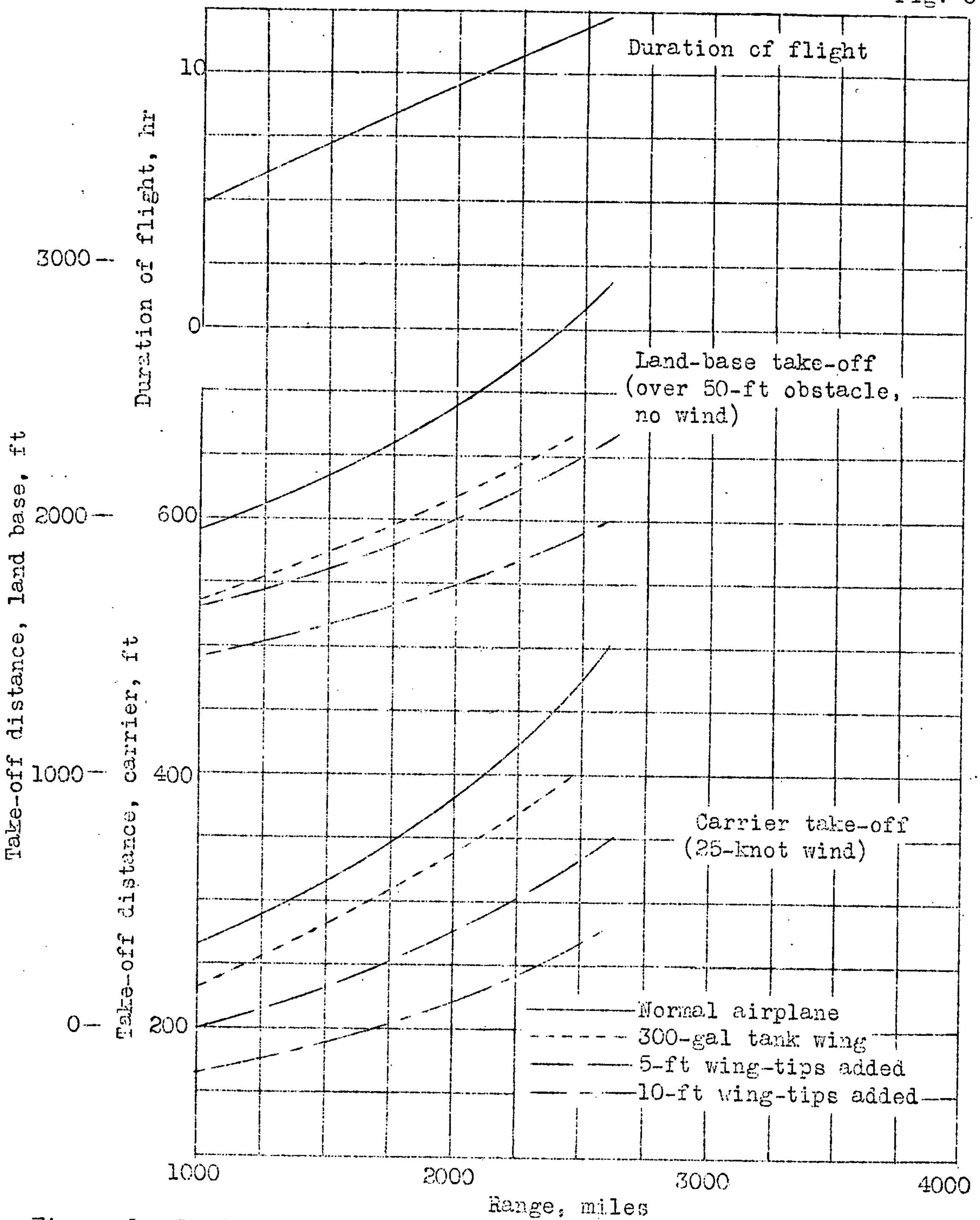

Figure 6.- Variation with range of take-off distances from a land base and a carrier and duration of flight for various modifications of fighter airplane. Flight at 10,000 feet at speed of maximum $\eta/C \cdot L/D$ of normal airplane for all conditions.