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Dir., Aeronautics  
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*10-1-46*

*Boeing*  
*10-1-46*

# RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

ALTITUDE-WIND-TUNNEL INVESTIGATION OF OIL-SYSTEM

PERFORMANCE OF XR-4360-8 ENGINE

IN XTB2D-1 AIRPLANE

By

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

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ALTITUDE-WIND-TUNNEL INVESTIGATION OF OIL-SYSTEM PERFORMANCE

OF XR-4360-8 ENGINE IN XTB2D-1 AIRPLANE

By E. William Conrad

## SUMMARY

An investigation was conducted in the Cleveland altitude wind tunnel to determine the aerodynamic characteristics and the oil-delivery critical altitude of the oil-cooler installation of an XTB2D-1 airplane. The investigation was made with the propeller removed and with the engine operating at 1800 brake horsepower, an altitude of 15,000 feet (except for tests of oil-delivery critical altitude), oil-cooler flap deflections from  $-20^{\circ}$  to  $20^{\circ}$ , and inclinations of the thrust axis of  $0^{\circ}$ ,  $1.5^{\circ}$ , and  $6^{\circ}$ .

At an inclination of the thrust axis of  $0^{\circ}$  and with the propeller operating, the total-pressure recovery coefficient at the face of the oil cooler varied from 0.84 to 1.10 depending on the flap deflection. With the propeller removed, the best pressure recovery at the face of the oil cooler was obtained at an inclination of the thrust axis of  $1.5^{\circ}$ .

Air-flow separation occurred on the inner surface of the upper lip of the oil-cooler duct inlet at an inclination of the thrust axis of  $0^{\circ}$  and on the inner surface of the lower lip at  $6^{\circ}$ . Static-pressure coefficients over the duct lips were sufficiently low that no trouble from compressibility would be encountered in level flight. The oil-delivery critical altitude at cruising power (2230 rpm, 1675 bhp) was approximately 18,500 feet for the oil system tested.

## INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, the altitude performance of the XR-4360-8 engine installed in the

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XTB2D-1 airplane has been investigated with a full-scale model in the Cleveland altitude wind tunnel. Aerodynamic studies of the cowl inlet and the carburetor duct are presented in reference 1.

The performance of the XTB2D-1 oil-cooler duct installation presents special problems because of the geometric limitations imposed by the requirements that the installation be located ahead of the front spar and that round oil coolers be used to permit interchangeability. Data on aerodynamic characteristics of the oil-cooler installation were obtained in the wind tunnel at a simulated altitude of 15,000 feet, with the propeller removed and with the engine operating at 1800 brake horsepower, at inclinations of the thrust axis of  $0^{\circ}$ ,  $1.5^{\circ}$ , and  $6^{\circ}$ . The oil-cooler flap deflection was varied from  $-20^{\circ}$  to  $20^{\circ}$ .

The oil-delivery critical altitude is defined as that altitude, dependent on engine operating conditions, at which a rapid decrease in engine oil pressure caused by oil aeration will accompany any further increase in altitude. Test runs were conducted up to a pressure altitude of approximately 19,000 feet to determine this critical altitude.

#### DESCRIPTION OF MODEL

A full-scale model of the XTB2D-1 airplane was used in the tests. In order to permit installation in the 20-foot-diameter test section of the Cleveland altitude wind tunnel, the ends of the wings were cut off and the fuselage length was reduced by shortening the tapered section behind the canopy. No tail group was installed on the model. The power plant for this airplane is an XR-4360-8 engine, which is an air-cooled, 28-cylinder, radial engine, having four rows of seven cylinders each, with a normal rated power of 2500 brake horsepower at an engine speed of 2550 rpm and a take-off power of 3000 brake horsepower at an engine speed of 2700 rpm. The installation included two counterrotating four-bladed propellers 14 feet in diameter and operating at 0.425 engine speed.

Two 16-inch-diameter oil coolers coupled in parallel were located in ducts, one in each wing, as shown in figures 1 and 2. The oil coolers are set at an angle of  $45^{\circ}$  to the wing chord line. Figure 3 is a calibration curve for the oil-cooler flap. A schematic drawing of the oil-piping system is shown in figure 4. Neither the volumetric flowmeter nor the breather dump tank is part of the production oil system. The capacities of the oil tank and the breather dump tank are 80 and 20 gallons, respectively.

## INSTRUMENTATION

The points at which oil temperature was measured are indicated in figure 4. Twelve total-pressure measurements of the cooling air were taken at the front face of the right oil cooler and four static-pressure measurements were taken at the rear face. No instrumentation was installed on the oil cooler in the left wing because counter-rotating propellers were used and none of the usual slipstream-rotation effects encountered with single-rotation propellers were anticipated. The right oil cooler was rotated  $20^\circ$  from its normal position to provide space for the pressure-tube leads; the tubes described as being in a vertical or a horizontal plane were therefore actually in planes  $20^\circ$  from vertical and horizontal. (See fig. 1.) A static belt of 12 tubes was installed on each lip of the right oil-cooler duct (fig. 2(a)).

The drag of the installation was measured on the wind-tunnel recording scales. Brake horsepower was determined by means of a special torquemeter nose section furnished with the engine. The oil used throughout the test program was grade AN 1100.

## TEST PROCEDURE

A large part of the data on the oil system was obtained in conjunction with investigations of engine cooling, cowling, and carburetor-air-scoop performance; and the procedure was necessarily governed by the requirements of the primary investigations. Specific tests at a pressure altitude of 15,000 feet were made, however, to determine the performance of the oil system at 1800 brake horsepower and with the propeller removed.

Complete sets of pressure, temperature, drag, and lift data were taken at the following conditions:

Propeller	Inclination of thrust axis (deg)	Indicated airspeed (mph)	Oil-cooler flap deflections (deg)	Pressure altitude (ft)
Operating	0	225	-20,-10,-3 4,11,18	15,000
Removed	0,1.5 6	211 154	-20,-10,0 5,10,15,20	15,000

The oil-delivery critical altitude was determined by maintaining constant engine power and increasing the pressure altitude (decreasing the tunnel pressure) until the oil pressure was observed to decrease rapidly with further slight increases in altitude.

## SYMBOLS

The following symbols were used in presenting the data:

$\frac{\Delta D}{q_0}$	incremental-drag coefficient
$\frac{\Delta L}{q_0}$	incremental-lift coefficient
$\frac{H_2 - p_0}{q_{c0}}$	total-pressure recovery coefficient
$\frac{p - p_0}{q_0}$	static-pressure coefficient
$\frac{p_3 - p_0}{q_{c0}}$	static-pressure coefficient behind oil cooler
$\Delta D$	incremental drag, pounds
$H$	total pressure, pounds per square foot
$\Delta L$	incremental lift, pounds
$p$	static pressure, pounds per square foot
$\Delta p$	pressure drop across oil cooler ( $H_2 - p_3$ ), pounds per square foot
$q$	dynamic pressure, pounds per square foot
$q_c$	impact pressure, pounds per square foot
Subscripts:	
$0$	station ahead of propeller



- 1 station at duct entrance
- 2 station at front of oil cooler
- 3 station at rear of oil cooler

## RESULTS AND DISCUSSION

### Pressure Recovery

The total pressure recovery coefficient at the front of the oil cooler is expressed in terms of the impact pressure at a station ahead of the propeller. No corrections have been made for tunnel blocking or slipstream effects. The variation of pressure recovery in the propeller-removed tests for three inclinations of the thrust axis and several oil-cooler flap deflections is presented in figures 5 and 6. Little change in pressure recovery coefficient occurred along the horizontal plane but large variations occurred in the vertical plane.

The reduction of pressure recovery coefficient on the upper two-thirds of the oil cooler at an inclination of the thrust axis of  $0^\circ$  was pronounced (fig. 6(a)). The reduction at  $6^\circ$  (fig. 6(c)) occurred over the lower third of the oil cooler and was much greater than at  $0^\circ$ . These reductions resulted from separation of the air flowing over the lips of the duct; the separation occurred on the inner surface of the lower lip at an inclination of the thrust axis of  $6^\circ$  and on the inner surface of the upper lip at  $0^\circ$ .

At an inclination of the thrust axis of  $6^\circ$  (fig. 6(c)), the point at which the losses suddenly increased moved downward along the face of the oil cooler with increase in oil-cooler flap deflection. Separation occurred over the lower lip of the duct at all flap deflections.

The pressure recovery coefficients at the face of the oil cooler are plotted against oil-cooler flap deflection in figure 7. The pressure recovery coefficient varied from 0.686 to 0.99 for the range of air flows and the inclinations of the thrust axis tested. The highest average pressure recovery coefficients were obtained with an inclination of the thrust axis of  $1.5^\circ$ .

The pressure recovery coefficients with the propeller operating and with the propeller removed are compared in figure 8. The average pressure recovery coefficients at the face of the oil cooler were

from 11 to 20 percent higher with the propeller operating than with the propeller removed. With the engine operating at 1800 brake horsepower, pressure recovery coefficients from 0.84 to 1.10 were obtained.

The effect of the angularity between radiator core passages and the direction of flow of the impinging air has been investigated (references 2 and 3) and the losses resulting from such angularity were found to be relatively small. Pressure-drop increases of approximately 5 percent were indicated for an oil cooler set at  $45^\circ$  to the impinging air stream. When the oil cooler was set at a  $45^\circ$  angle, the flow area increased about 40 percent with an increased pressure drop of only 5 percent and no increase in duct length was required.

The variation of the static-pressure coefficient behind the right oil cooler with flap deflection is shown in figures 9 and 10. Figure 9 shows the effect of changes in inclination of the thrust axis and figure 10 presents a comparison of propeller-removed and propeller-operating conditions. The effects of inclination of the thrust axis and of propeller operation on the pressure drop across the oil cooler are presented in figures 11 and 12, respectively, in which pressure-drop coefficient is plotted against oil-cooler flap deflection.

#### Lift and Drag

Inasmuch as no tests were made with the oil-cooler duct openings faired and sealed, the total lift and drag associated with the oil-cooler installation could not be determined. Variations of lift and of drag with oil-cooler flap deflection were measured, however, and are shown in figures 13 and 14, respectively. The incremental drag and lift of the oil-cooler installation were calculated by subtracting an arbitrary reference value from the measured drag or lift; the reference value was the lowest drag or lift for any condition of a series of tests in which only the oil-cooler flap deflection was changed. Both lift and drag increased at large flap deflections. Minimum values for each were obtained at flap deflections from  $-3^\circ$  to  $-10^\circ$ . At smaller flap deflections, both lift and drag again increased.

Results obtained with static-pressure survey belts over the duct lips show that very small variations of pressure distribution resulted from changes in flap deflection and that large variations

resulted from changes in the inclination of the thrust axis (fig. 15). The maximum negative static-pressure coefficients on the oil-cooler duct lips were small and indicated that no critical velocities over these surfaces would be encountered in level flight.

#### Oil-Delivery Critical Altitude

When the engine was operated at 1675 brake horsepower and 2230 rpm, the oil-delivery critical altitude was approximately 18,500 feet. Although the oil-delivery critical altitude was 18,500 feet, the oil-system performance was not necessarily satisfactory up to that altitude; considerable amounts of oil passed through the breather into the dump tank (fig. 4) during tests at 15,000 feet. The oil-delivery performance of the production oil system should be slightly better than the system tested because the pressure drop caused by the volumetric flowmeter had a detrimental effect on the oil-delivery characteristics. The pressure drop of the volumetric flowmeter, as estimated from data furnished by the manufacturer, is 0.15 pound per square inch at this power condition. When corrected for this pressure drop, the oil-delivery critical altitude is 19,000 feet.

The oil-delivery critical altitude for any given pump design is largely determined by the amount of air by volume in the oil at the pump inlet. The theory presented in reference 4 indicates that the oil-delivery critical altitude of the XTB2D-1 production oil system could be improved by the use of a larger line from the tank to the pump inlet or by pressurizing the oil tank. The position of the filter (fig. 4) in the XTB2D-1 oil system is poor from the aeration aspect because large bubbles leaving the scavenge pump are broken up into many small bubbles that are very stable and very slow to separate in the oil tank. Location of the oil filter in the line from the tank to the engine would be worse than the present location because the pressure drop in the line would be increased. The ideal location would be between the pressure pump and the pressure-relief valve but the pump housing of the engine would have to be redesigned to permit such an installation.

#### SUMMARY OF RESULTS

The oil-cooler installation of the XTB2D-1 airplane was investigated with the propeller removed and at 1800 brake horsepower, pressure altitudes up to 19,000 feet, oil-cooler flap deflections from  $-20^{\circ}$  to  $20^{\circ}$ , and inclinations of the thrust axis of  $0^{\circ}$ ,  $1.5^{\circ}$ , and  $6^{\circ}$ . The following results were obtained:



1. At an inclination of the thrust axis of  $0^\circ$  and with the engine operating at 1800 brake horsepower, the pressure recovery coefficient at the face of the oil cooler varied from 0.84 to 1.10 depending on the flap deflection. With the propeller removed, the best pressure recovery coefficient at the face of the oil cooler was obtained at an inclination of the thrust axis of  $1.5^\circ$ .

2. Separation of the air occurred on the inner surface of the upper lip of the oil-cooler duct at an inclination of the thrust axis of  $0^\circ$  and on the inner surface of the lower lip at  $6^\circ$ .

3. Pressure coefficients over the duct lips were sufficiently low that no trouble from compressibility would be encountered in level flight.

4. The oil-delivery critical altitude at cruising power (2230 rpm, 1675 bhp) was approximately 18,500 feet for the oil system tested.

Aircraft Engine Research Laboratory,  
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Earl W. Conrad,  
Mechanical Engineer.

Approved:

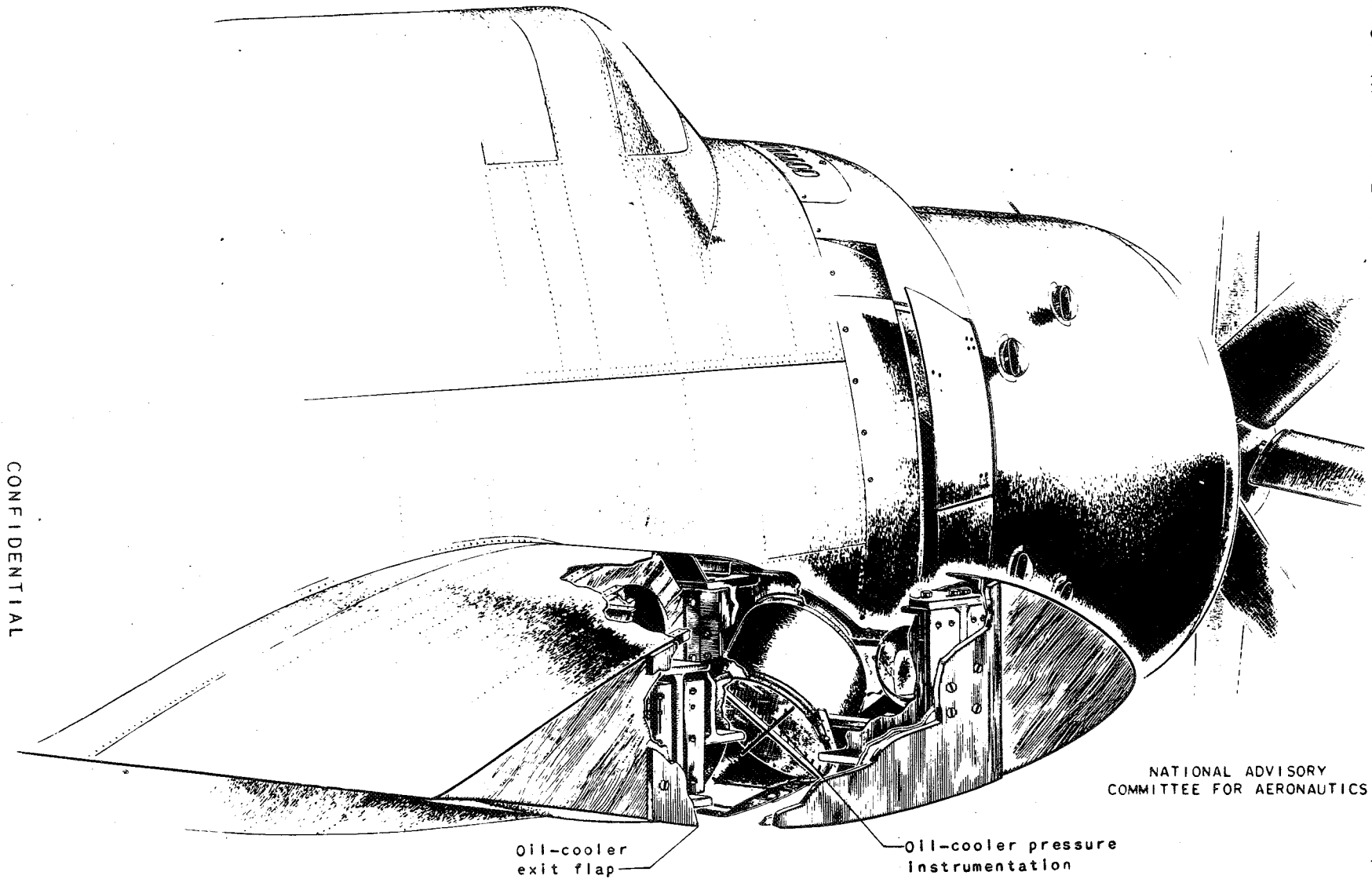
*Alfred W. Young*  
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*Abe Silverstein*  
Abe Silverstein,  
Aeronautical Engineer.

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2. Henry, John R.: Design of Power-Plant Installations - Pressure-Loss Characteristics of Duct Components. NACA ARR No. L4F26, 1944.
3. Nichols, Mark R.: Investigation of Flow through an Intercooler Set at Various Angles to the Supply Duct. NACA ARR, April 1942.
4. Pigott, R. J. S.: Oil Aeration. SAE Jour. (Trans.), vol. 52, no. 3, March 1944, pp. 73-84.

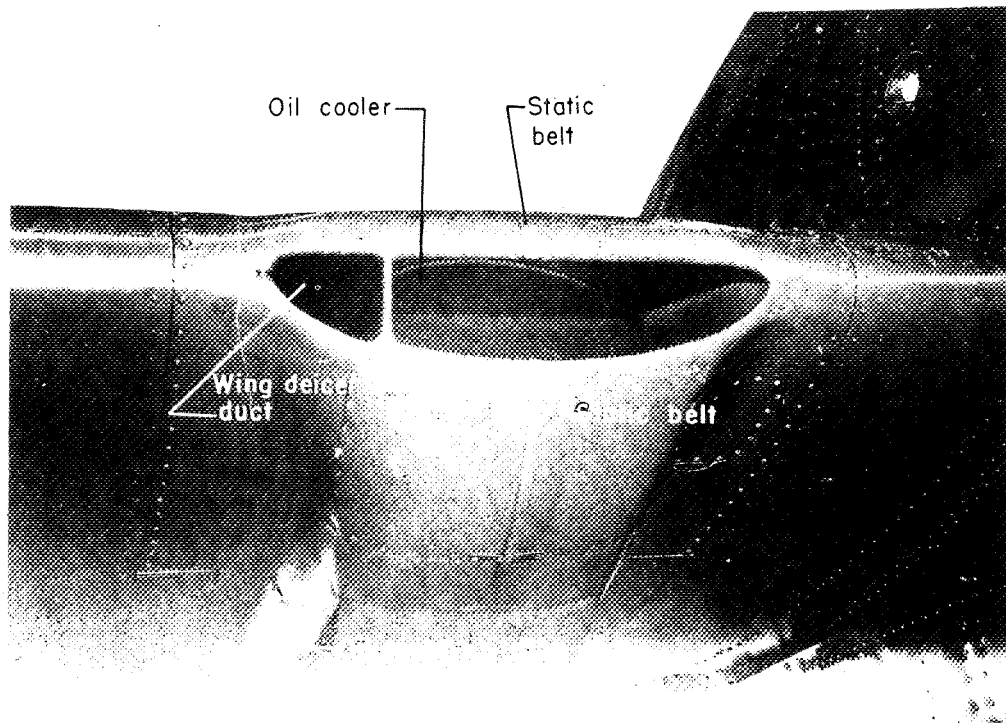


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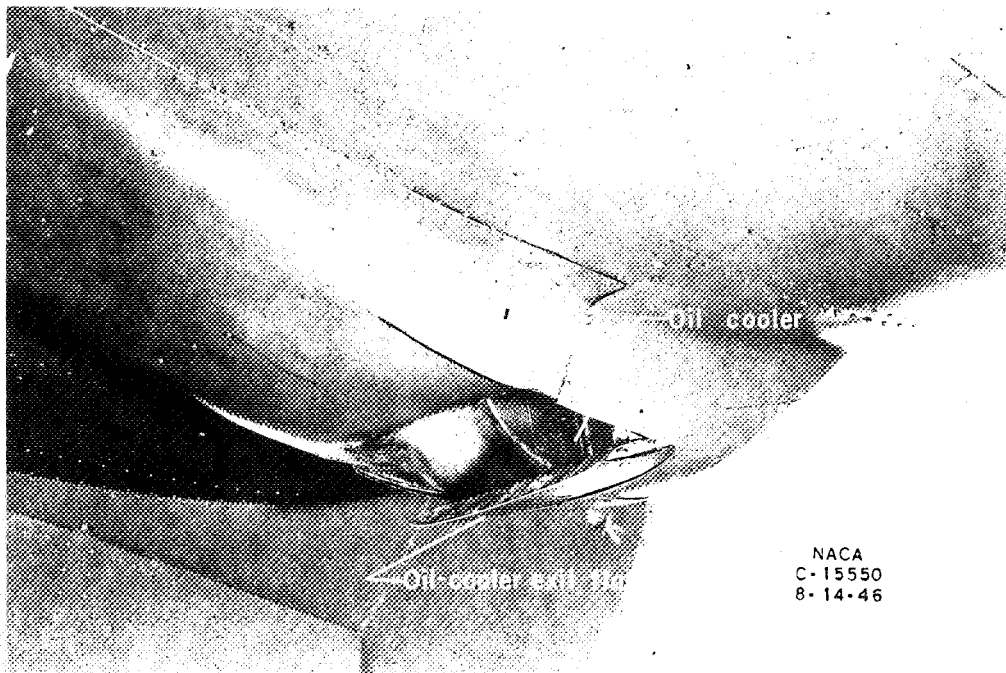
Oil-cooler  
exit flap

Oil-cooler pressure  
instrumentation

Figure 1. - Sketch of XT82D-1 full-scale model showing oil-cooler installation.



(a) Front view.



(b) Rear view.

Figure 2. — XTB2D-1 oil-cooler duct.

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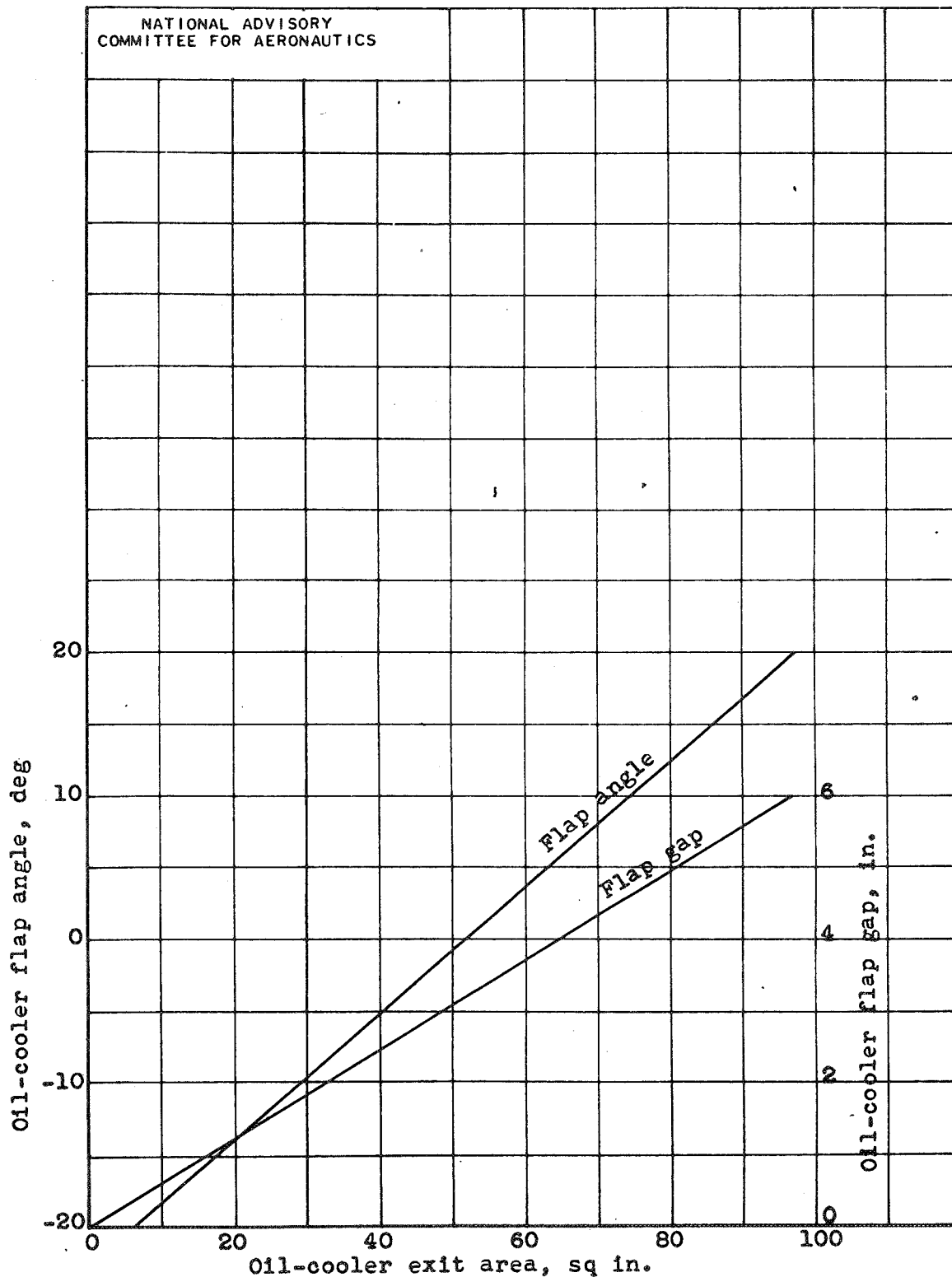
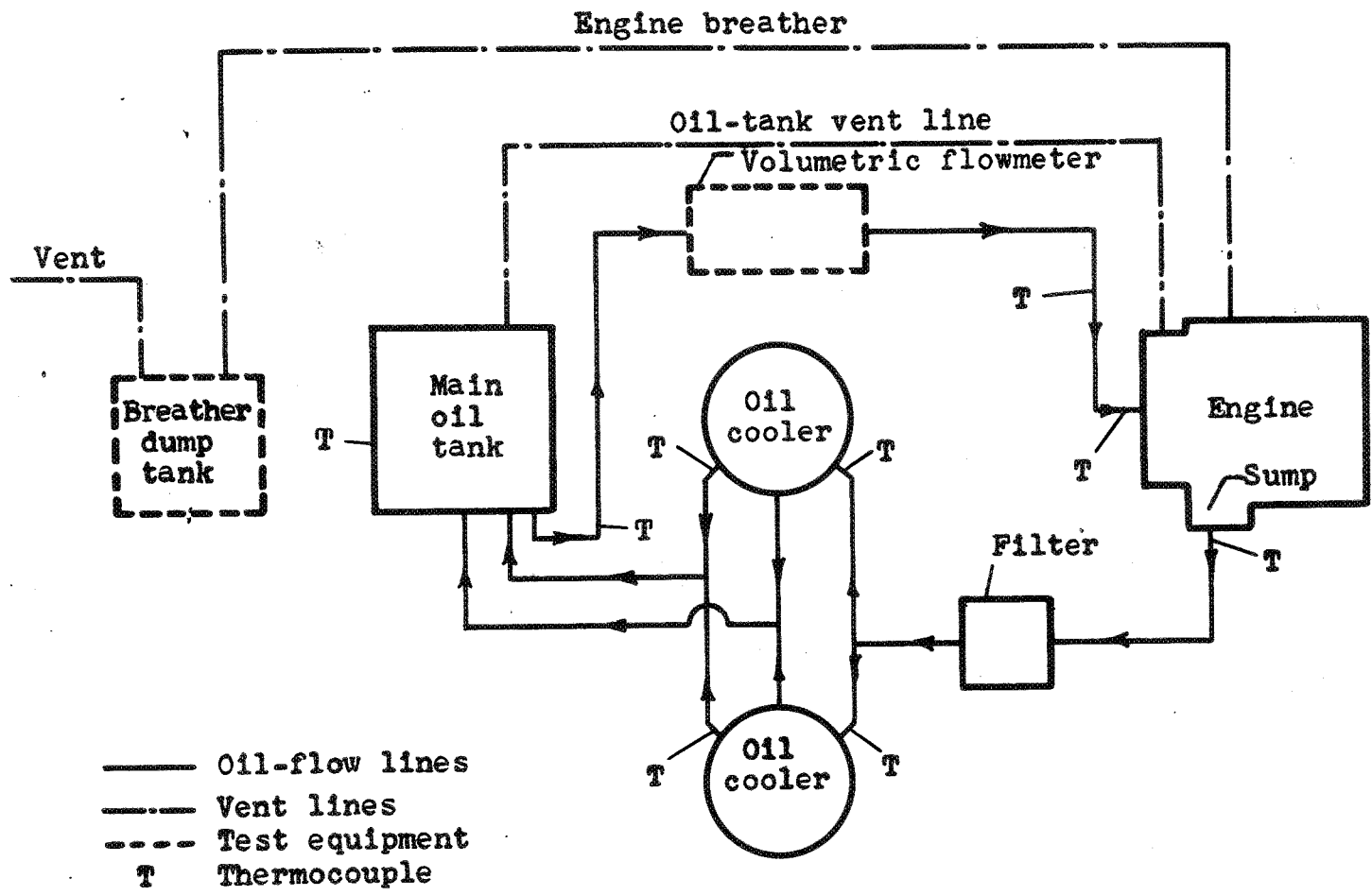


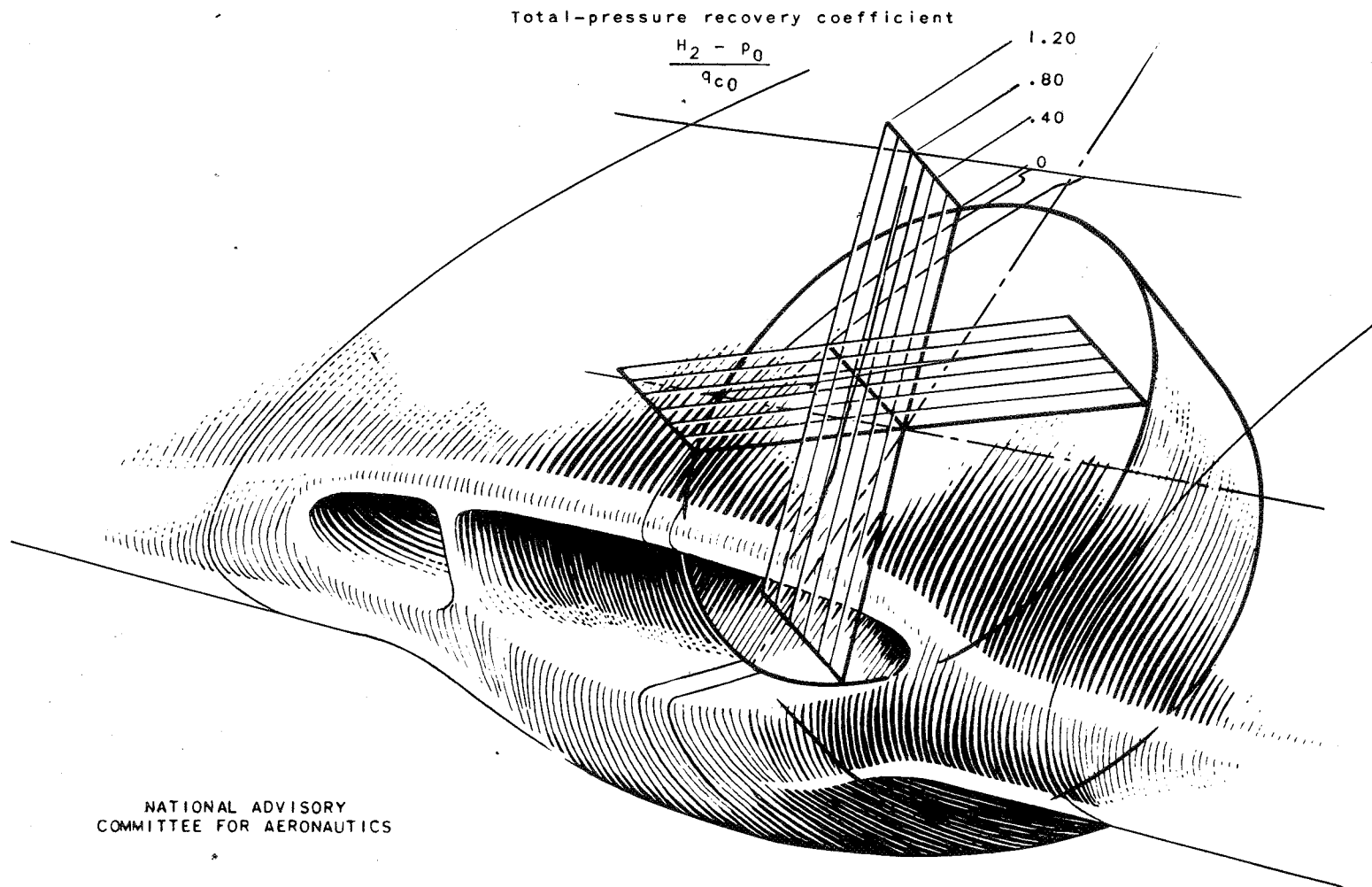
Figure 3.- Oil-cooler flap calibration for XTB2D-1 full-scale model.



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Figure 4.- Schematic drawing of oil system installed in XTB2D-1 full-scale model.





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(a) Inclination of the thrust axis,  $0^\circ$ .

Figure 5. - Total-pressure recovery coefficient at face of oil cooler  $\frac{H_2 - P_0}{q_{c0}}$  of

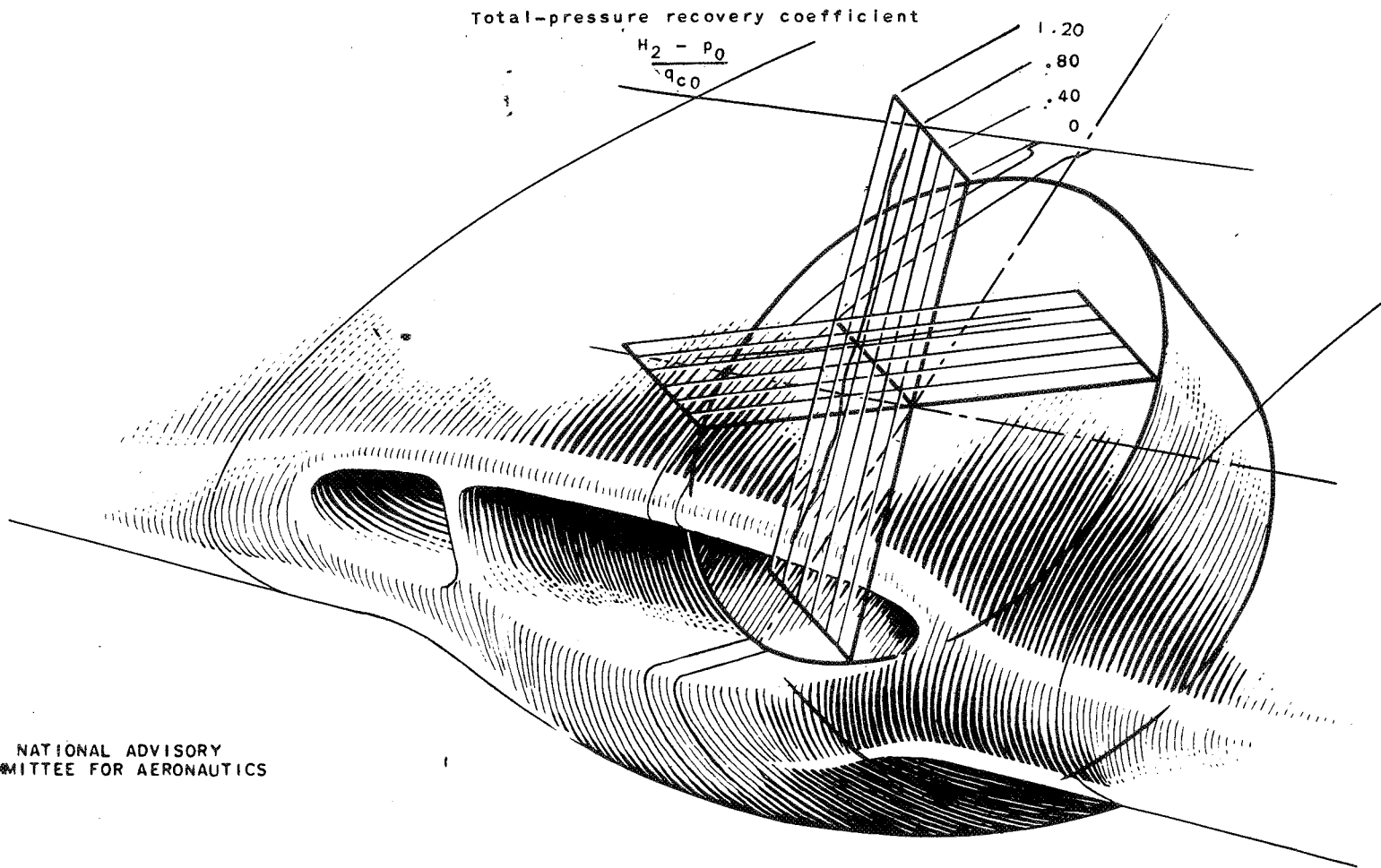
XTB2D-1 full-scale model. Propeller removed; pressure altitude, 15,000 feet; oil-cooler flap deflection,  $10^\circ$ .

Total-pressure recovery coefficient

$$\frac{H_2 - P_0}{q_{c0}}$$

1.20  
.80  
.40  
0

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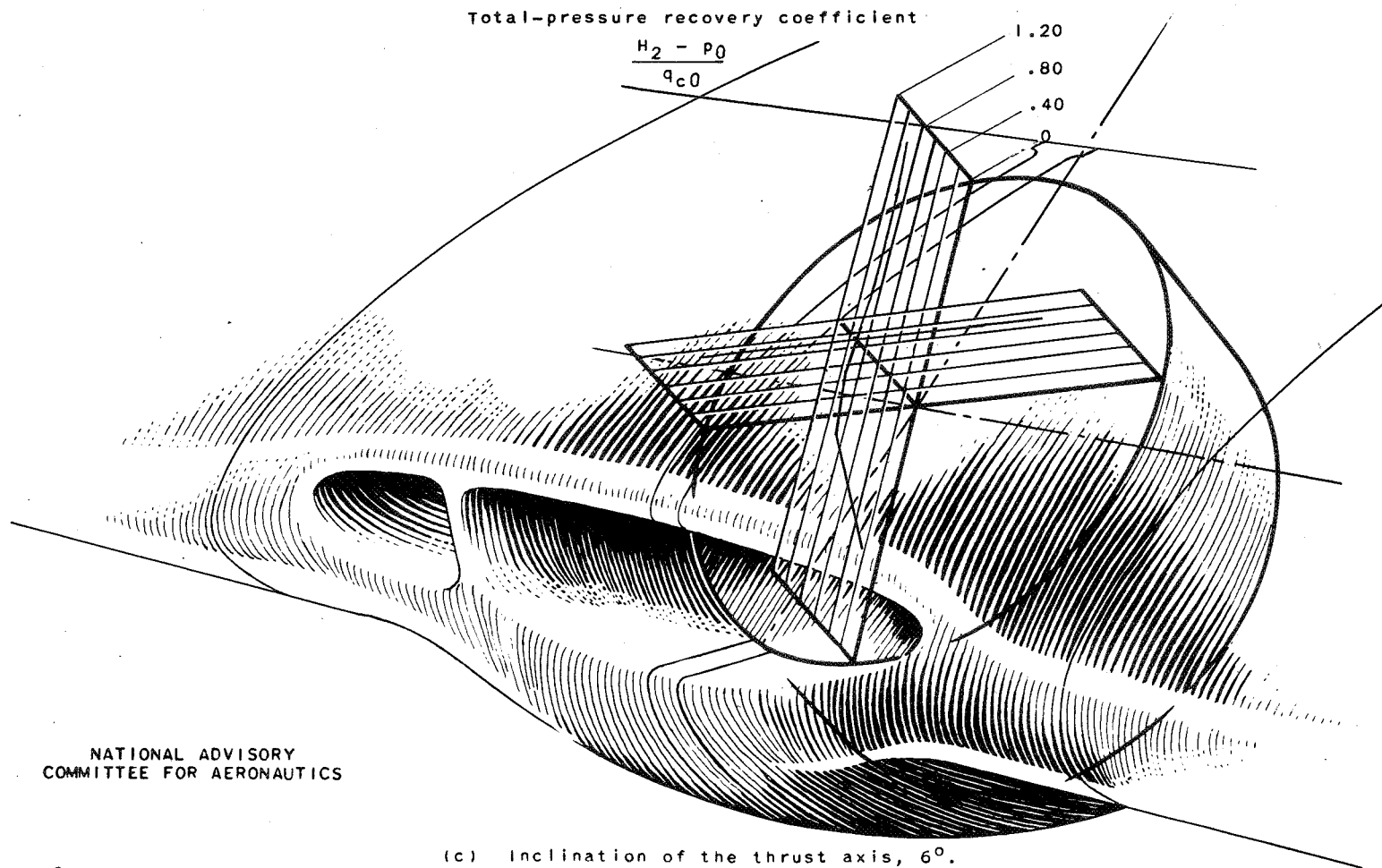
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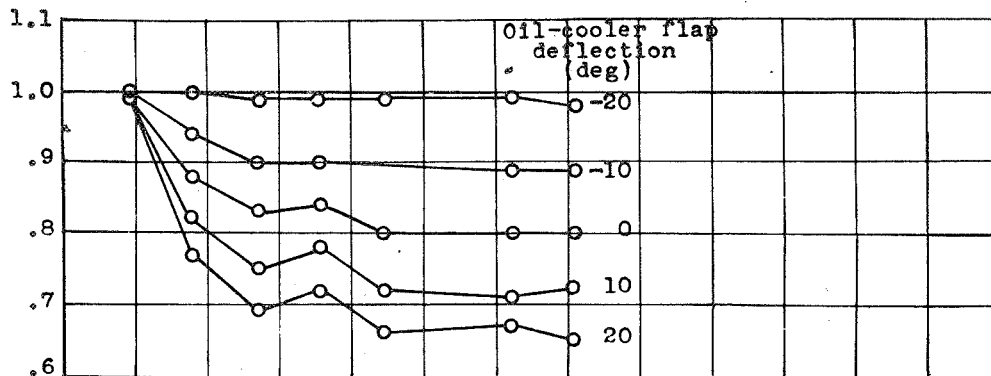
(b) Inclination of the thrust axis,  $1.5^\circ$ .

Figure 5. - Continued. Total-pressure recovery coefficient at face of oil cooler  $\frac{H_2 - P_0}{q_{c0}}$  of XT82D-1 full-scale model. Propeller removed; pressure altitude, 15,000 feet; oil-cooler flap deflection,  $10^\circ$ .

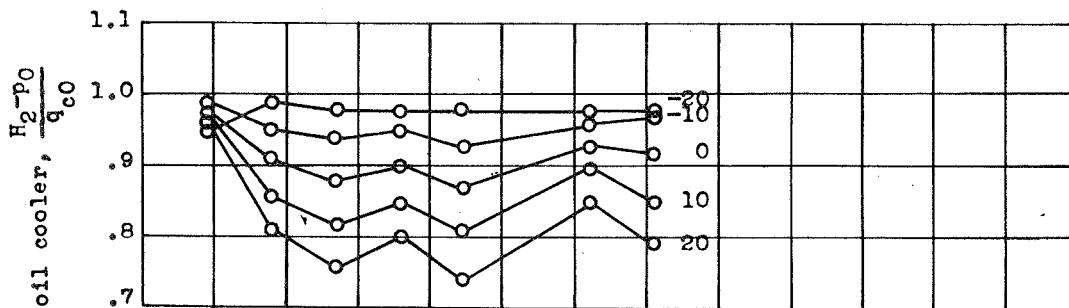


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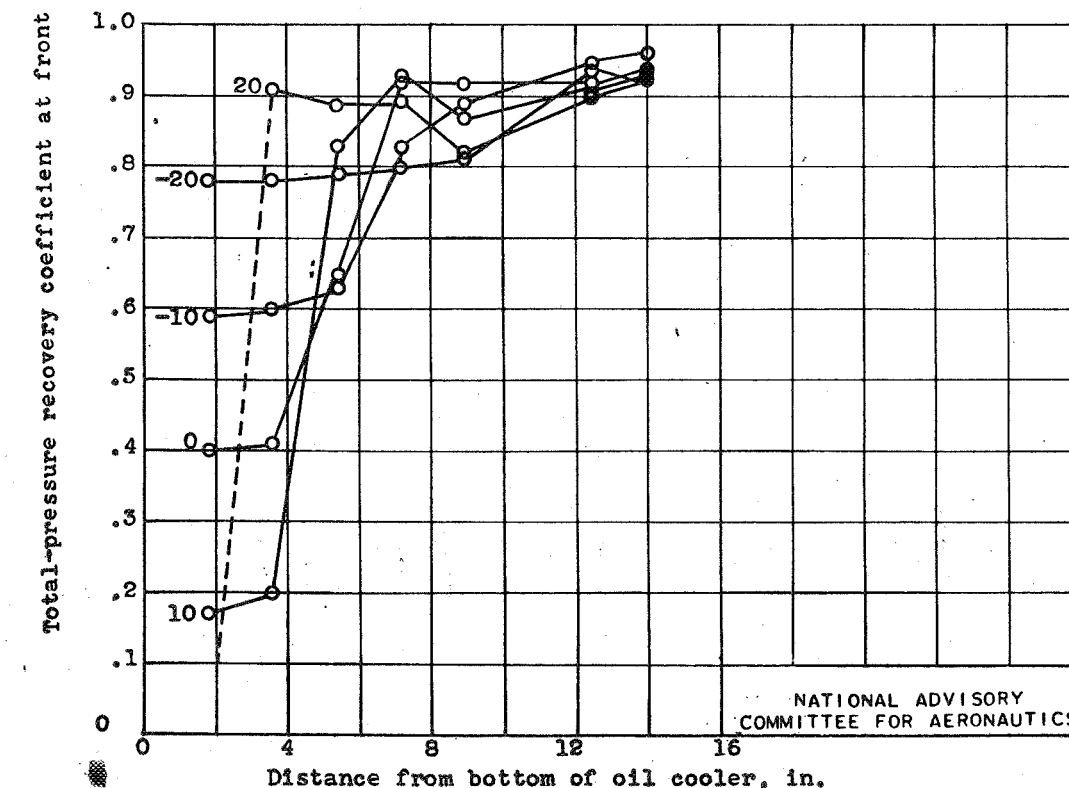
Figure 5. - Concluded. Total-pressure recovery coefficient at face of oil cooler  $\frac{H_2 - P_0}{q_{c0}}$  of XTB2D-1 full-scale model. Propeller removed; pressure altitude, 15,000 feet; oil-cooler flap deflection,  $10^\circ$ .



(a) Inclination of thrust axis, 0°.



(b) Inclination of thrust axis, 1.5°.



(c) Inclination of thrust axis, 6°.

Figure 6.- Variation of pressure recovery coefficient from bottom to top of oil cooler at various oil-cooler flap deflections for XT82D-1 full-scale model. Propeller removed; pressure altitude, 15,000 feet.

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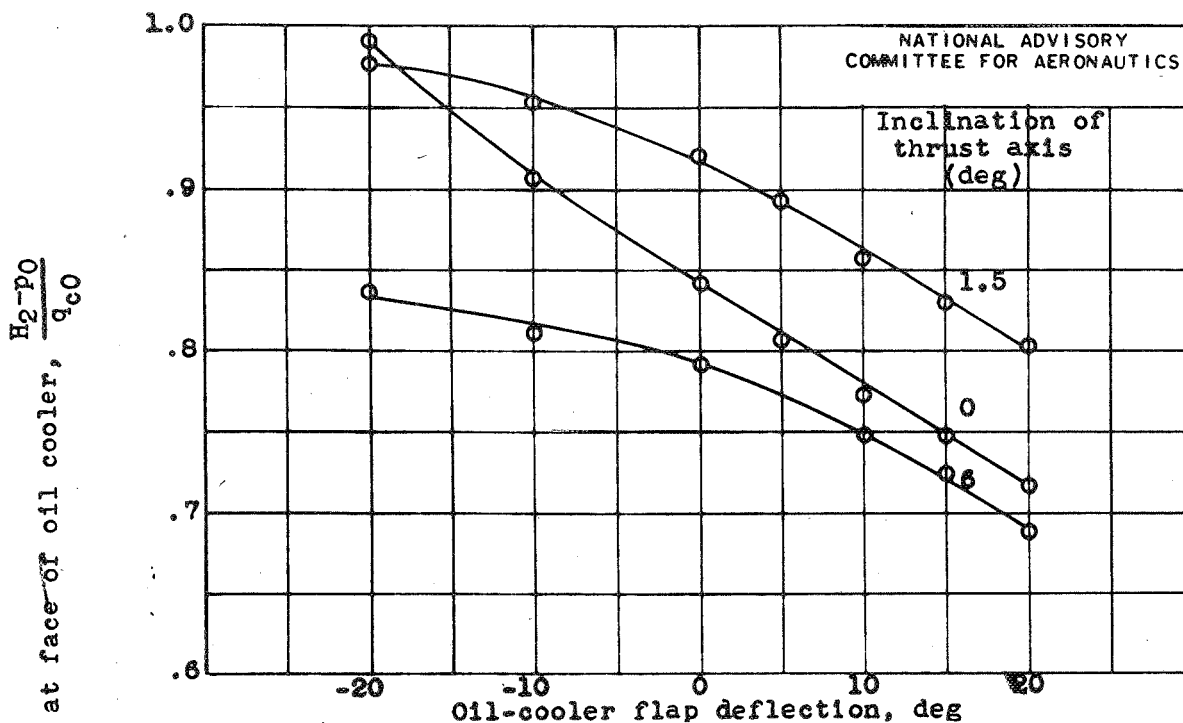


Figure 7.- Variation of pressure recovery coefficient with oil-cooler flap deflection for XTB2D-1 full-scale model at various inclinations of thrust axis. Propeller removed; pressure altitude, 15,000 feet.

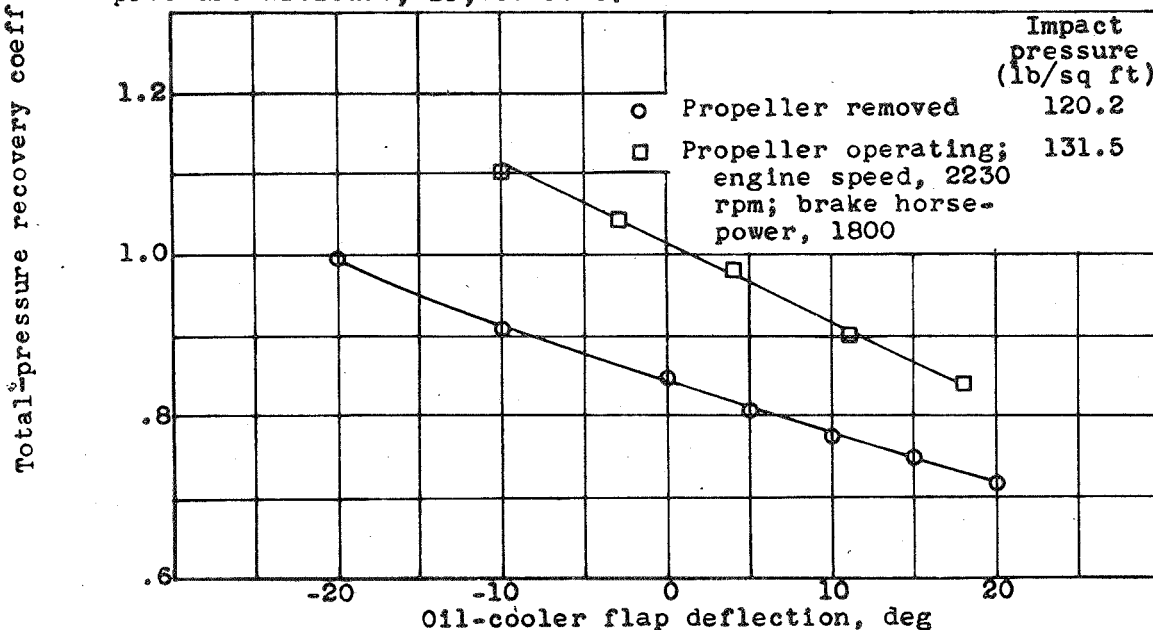


Figure 8.- Variation of pressure recovery coefficient with oil-cooler flap deflection for XTB2D-1 full-scale model with propeller removed and propeller operating. Pressure altitude, 15,000 feet; inclination of thrust axis, 0°.

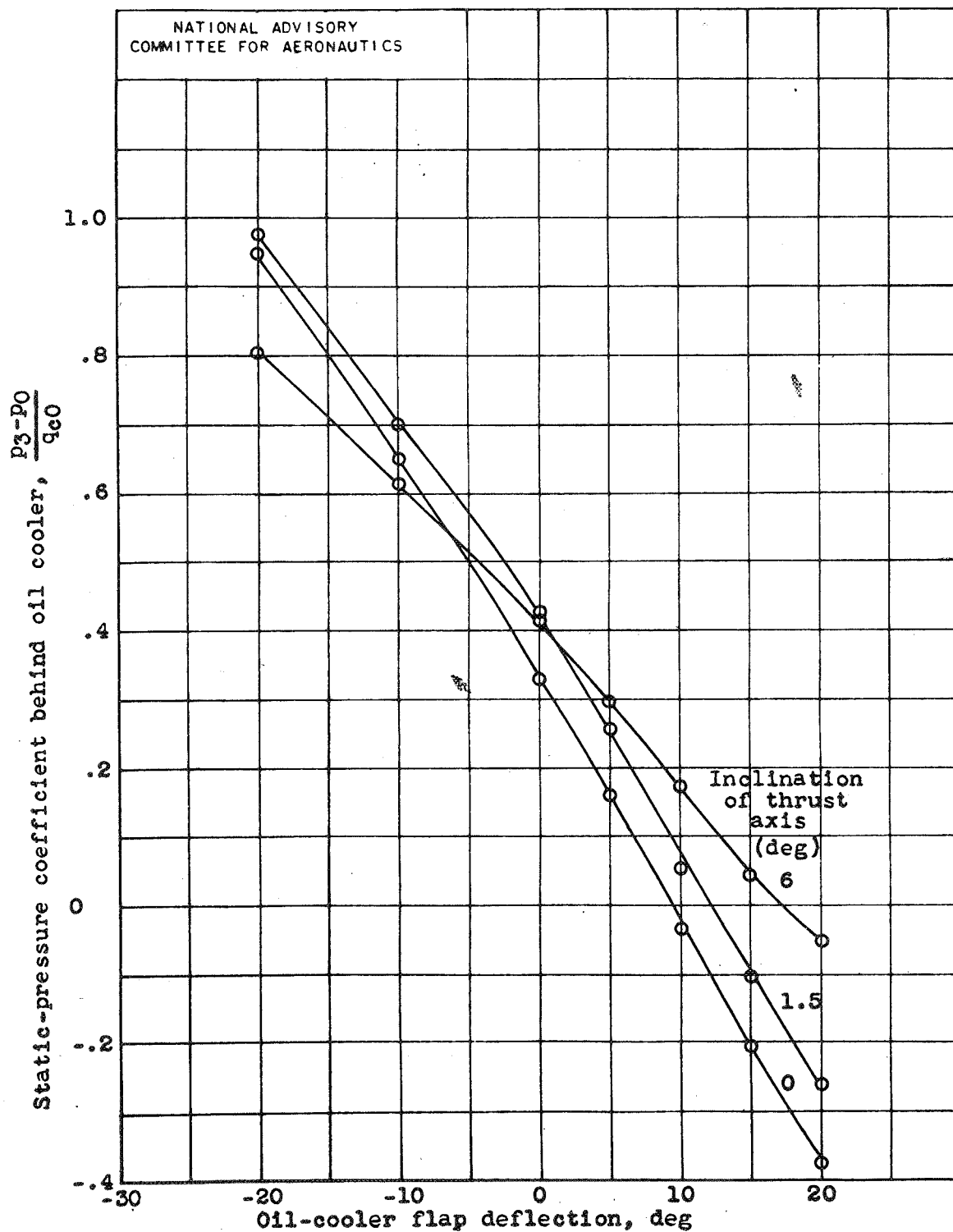


Figure 9.- Variation of static-pressure coefficient behind oil cooler with oil-cooler flap deflection for XT82D-1 full-scale model at various inclinations of thrust axis. Propeller removed; pressure altitude, 15,000 feet.



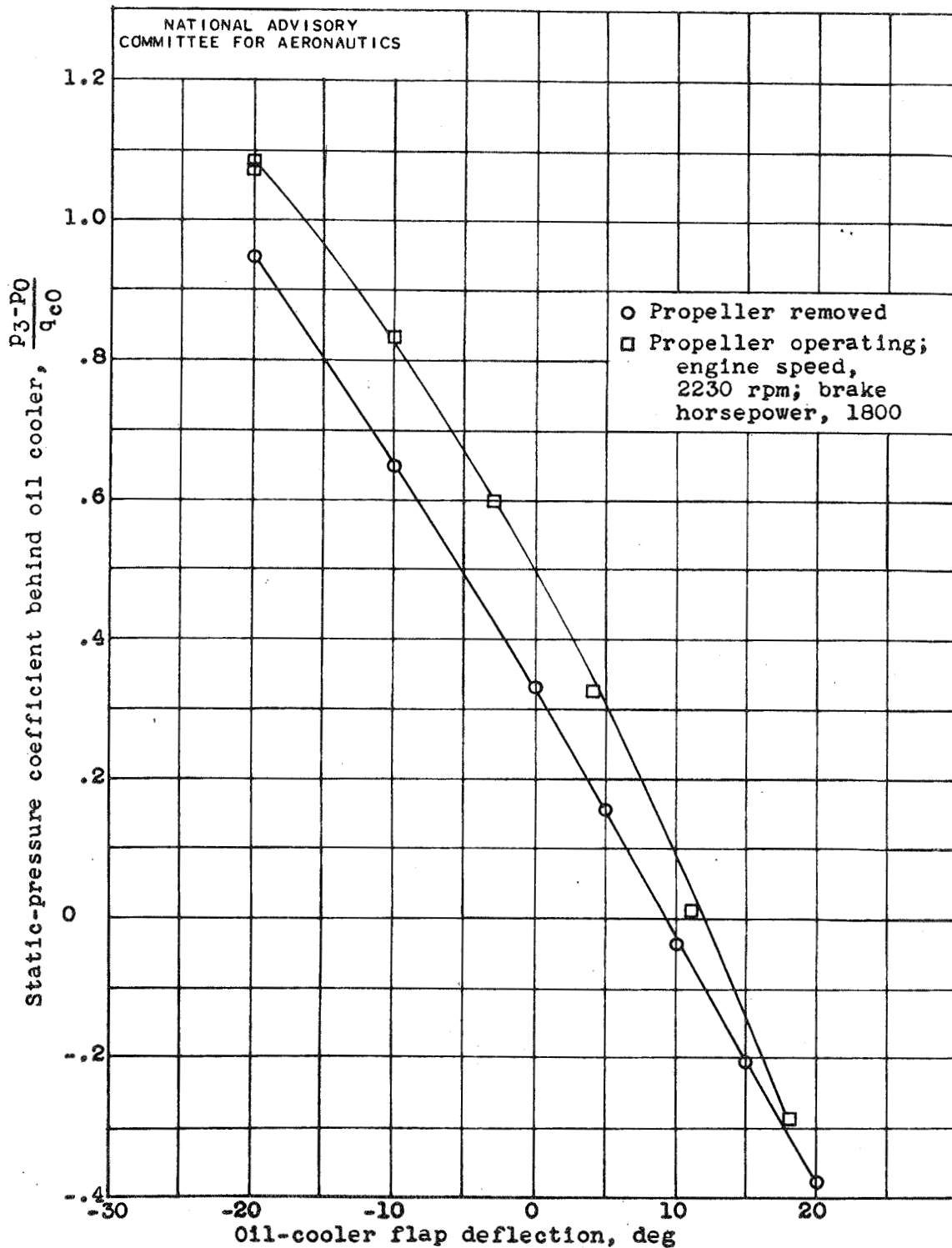


Figure 10.- Variation of static-pressure coefficient behind oil cooler with oil-cooler flap deflection for XTB2D-1/2 full-scale model with propeller removed and propeller operating. Pressure altitude, 15,000 feet; inclination of thrust axis, 0°.

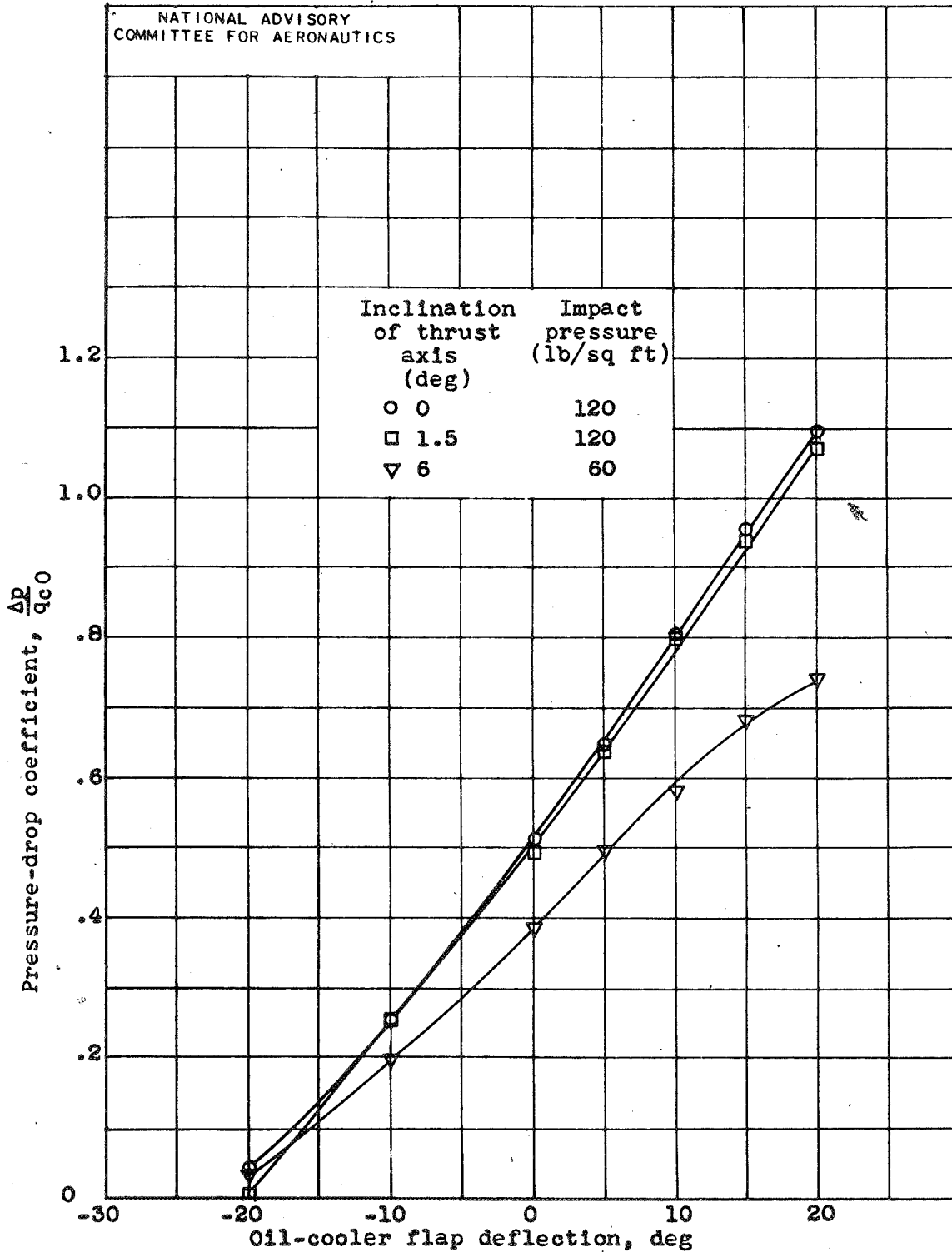


Figure 11.- Variation of pressure-drop coefficient across oil cooler with oil-cooler flap deflection for XTB2D-1 full-scale model at various inclinations of thrust axis. Propeller removed.

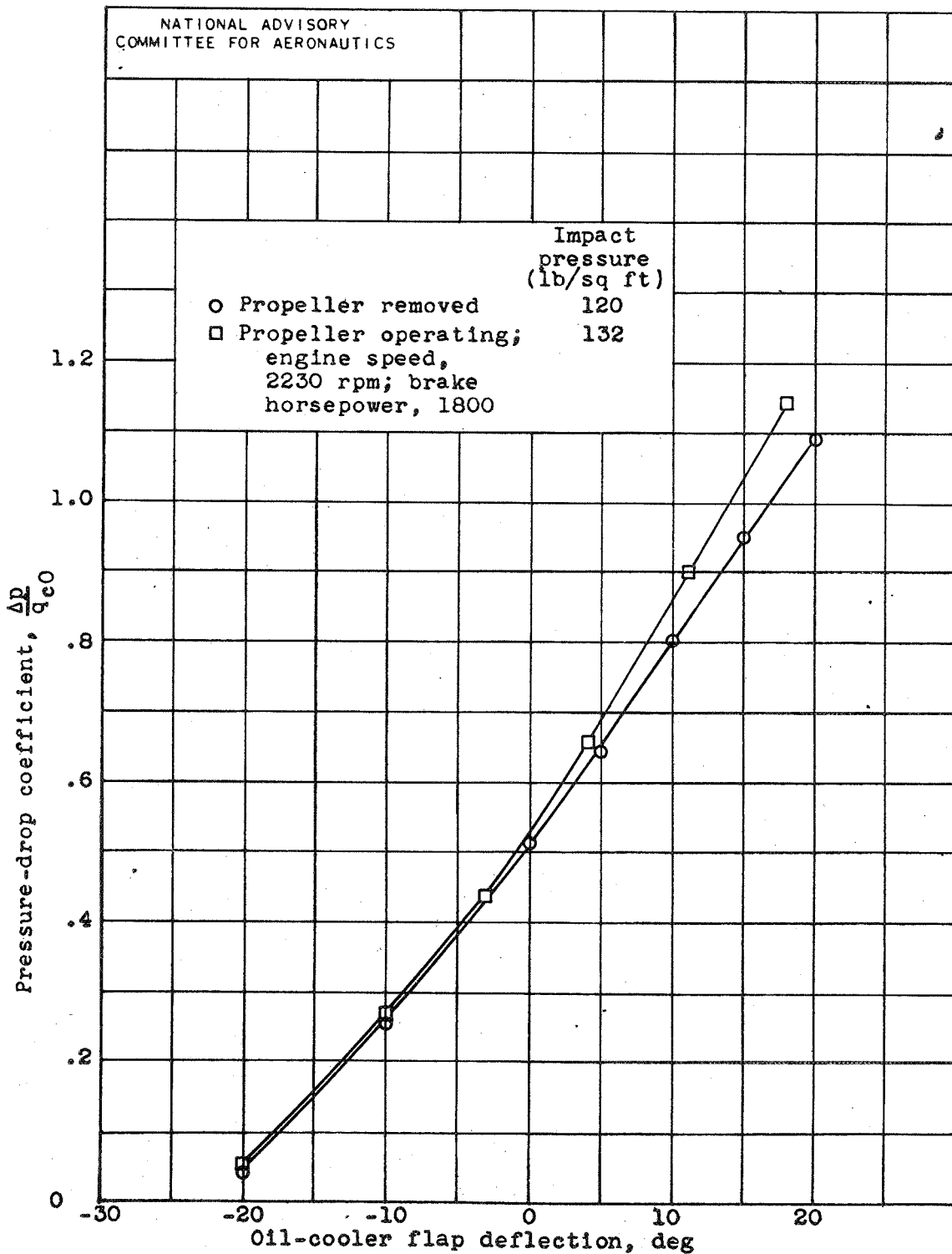


Figure 12.- Variation of pressure-drop coefficient across oil cooler with oil-cooler flap deflection for XTB2D-1 full-scale model with propeller removed and propeller operating. Pressure altitude, 15,000 feet; inclination of thrust axis, 0°.

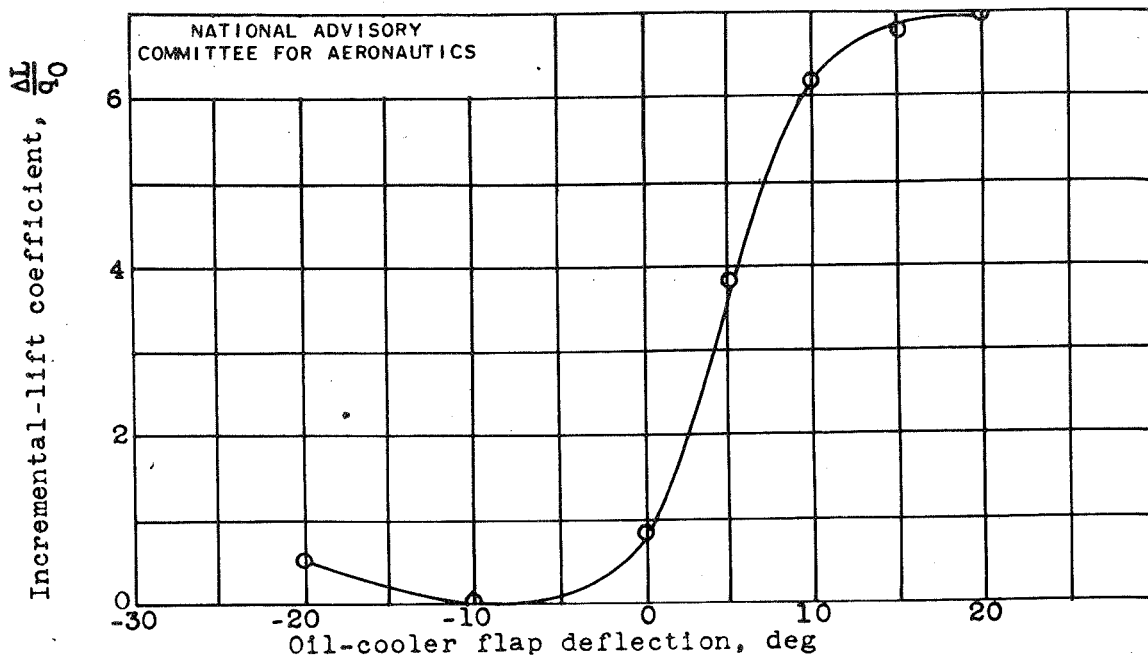


Figure 13.- Variation of incremental-lift coefficient with oil-cooler flap deflection for XTBD-1 full-scale model. Propeller removed; pressure altitude, 15,000 feet; inclination of thrust axis, 0°.

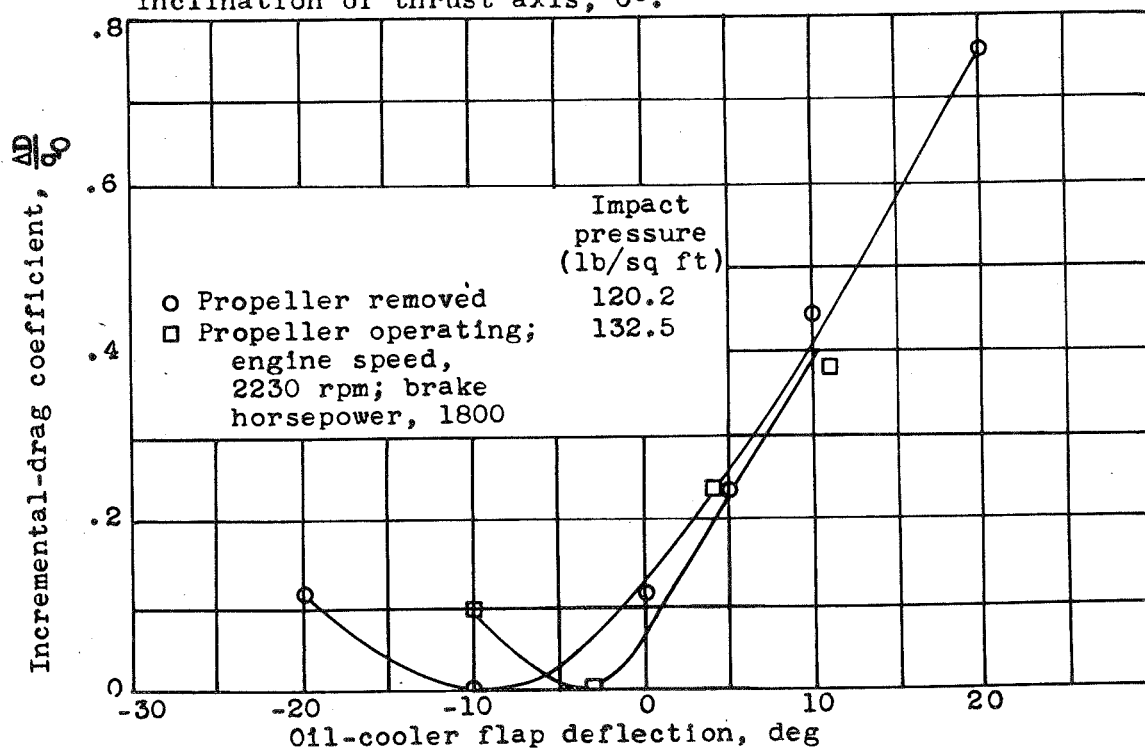


Figure 14.- Variation of incremental-drag coefficient with oil-cooler flap deflection for XTBD-1 full-scale model with propeller removed and propeller operating. Pressure altitude, 15,000 feet; inclination of thrust axis, 0°.

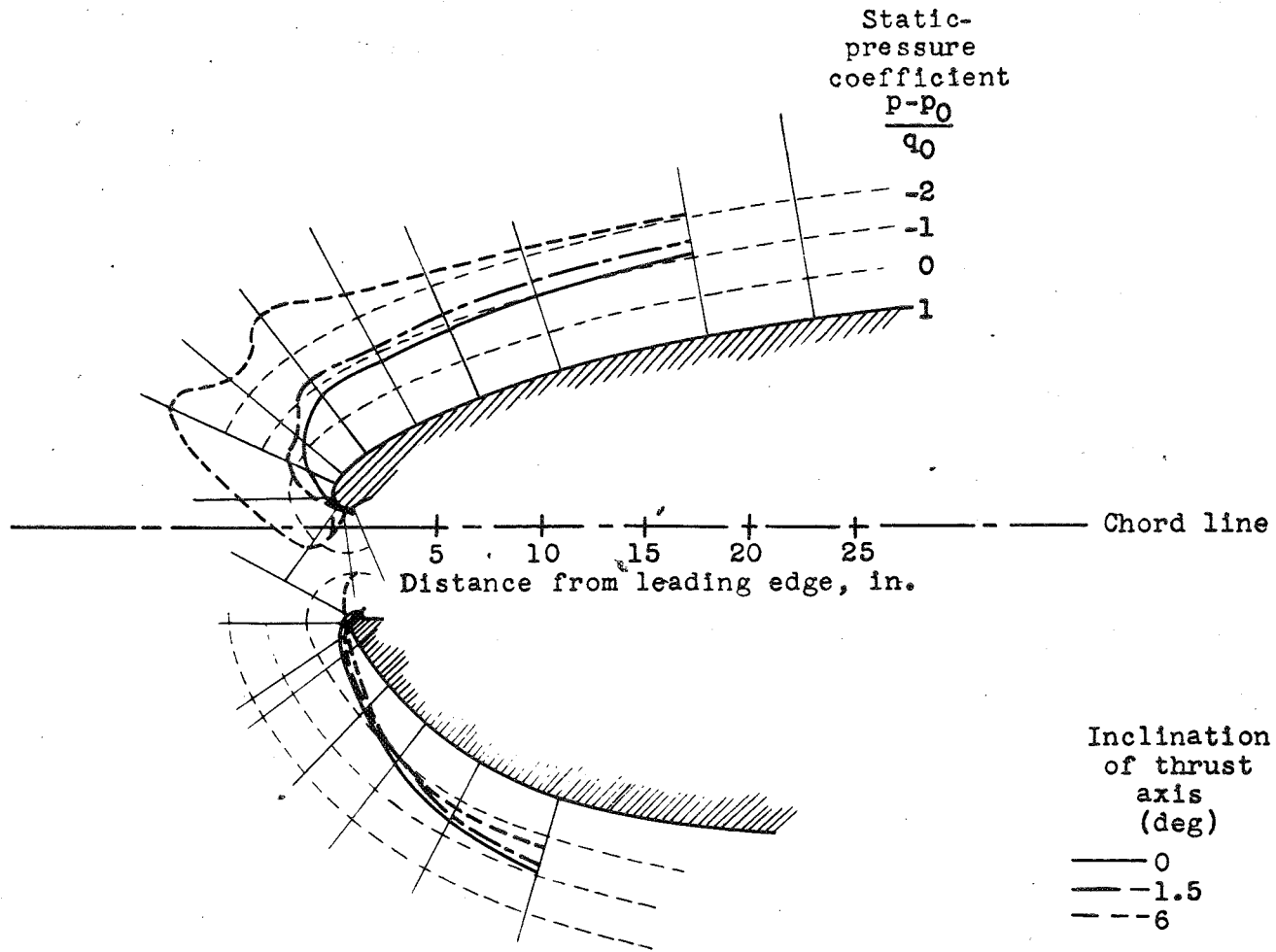


Figure 15.- Static-pressure survey over oil-cooler duct lips of XTBE2D-1 full-scale model. Propeller removed; pressure altitude, 15,000 feet; oil-cooler flap angle, 0°.

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