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AEDC-TR-67-265

EFFECTS OF REYNOLDS NUMBER VARIATION ON THE STABILITY AND AXIAL-FORCE CHARACTERISTICS OF A 0.0226-SCALE MODEL OF THE C-5A AIRCRAFT AT MACH NUMBERS 0.700, 0.767, AND 0.785

J. A. Black and T. O. Shadow
ARO, Inc.

December 1967

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FOREWORD

The work reported herein was done at the request of the Aeronautical Systems Division (ASD), Air Force Systems Command (AFSC), for the Lockheed-Georgia Company under Program Element 41119F.

The test results were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted from July 12 to 14, 1967, under ARO Project No. PB0760. The manuscript was submitted for publication on November 11, 1967.

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This technical report has been reviewed and is approved.

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ABSTRACT

Tests were conducted in the 16-ft transonic tunnel to determine the effects of Reynolds number variation on the aerodynamic characteristics of a 0.0226-scale model of the C-5A aircraft with fixed and free transition. The results show that Reynolds number variation from 2.1 to 4.2 million had little effect on the lift and pitching-moment coefficients and generally caused a decrease in drag coefficient.

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APPENDIX
Illustrations

NOMENCLATURE

A_b	Reference area of model base, 0.084 ft^2
C_{D_b}	Base drag coefficient, $\left(\frac{p_\infty - p_b}{q_\infty}\right)\left(\frac{A_b}{S}\right)\left(\cos\alpha\right)$
C_{D_F}	Forebody drag coefficient, forebody drag/$q_\infty S$
C_L	Lift coefficient, lift/$q_\infty S$
C_m	Pitching-moment coefficient, pitching moment/$q_\infty S\bar{c}$, moments referenced to a fuselage station coincident with the wing 25-percent mean aerodynamic chord
$\bar{c}$	Reference length of wing, 0.699 ft
M_∞	Free-stream Mach number
p_b	Model base pressure, psf
p_∞	Free-stream static pressure, psf
q_∞	Free-stream dynamic pressure, psf
Re	Reynolds number, $V_\infty \bar{c}/\nu_\infty$
S	Reference area of wing, 3.174 ft^2
V_∞	Free-stream velocity, ft/sec
α	Angle of attack of model reference plane, deg
$\Delta\alpha$	Test section flow angle measured from the tunnel centerline, positive upward, deg
ν_∞	Free-stream kinematic viscosity, ft^2/sec

MODEL NOMENCLATURE

Fuselage and Wing Assembly

B^{22}	Fuselage
W^{12}	Wing
Z^{f9}	Flap track fairings
Z^{G27}	Nose landing gear fairing
Z^{G28}	Main landing gear fairing
Z^{W27}	Wing fillet

Engine Assembly

K^{24}	Engine support pylon
N^{20}	Engine nacelle

Empennage Assembly

b^{16}	Bullet
D^{8}	Dorsal fin
H^{8}	Horizontal stabilizer
V^{9}	Vertical stabilizer

SECTION I
INTRODUCTION

A wind tunnel investigation of a 0.0226-scale model of the Lockheed-Georgia C-5A aircraft was conducted in the Propulsion Wind Tunnel, Transonic (16T). The tests were conducted at Mach numbers 0.700, 0.767, and 0.785, angles of attack from -3 to +3 deg, and Reynolds numbers of 2.1, 2.8, and 4.2 million based on the wing mean aerodynamic chord.

Previous test data obtained with 0.040-scale models (Refs. 1, 2, and 3) had indicated higher drag than that measured on 0.0226-scale models tested at other test facilities. In an attempt to determine the cause for the data differences, a testing technique and data correlation study was initiated to be conducted in the NASA-Ames Research Laboratory 11-ft Unitary Plan Wind Tunnel, the Cornell Aeronautical Laboratory 8-ft Transonic Tunnel, and the AEDC-PWT Tunnel 16T. The same support sting, internal strain-gage balance, and model were used at all test facilities, thus eliminating those items as potential causes of the differences. The test results reported herein constitute the AEDC-PWT portion of the correlation study.

SECTION II
APPARATUS

2.1 TEST FACILITY

Tunnel 16T is a variable density wind tunnel capable of operating at Mach numbers between 0.55 and 1.60. The tunnel is equipped with a plenum evacuation system, and the test section is formed by fixed, parallel top and bottom perforated walls and perforated variable angle sidewalls. A more complete description of the wind tunnel, its operating characteristics, and support equipment is given in Ref. 4. The results of the most recent calibration of the tunnel are provided in Ref. 5. The location of the test model and model support system in the test area is indicated in Fig. 1 (Appendix), and a photograph of the model installed in the tunnel is shown in Fig. 2.

2.2 TEST ARTICLE

Details of the 0.0226-scale C-5A model are presented in Fig. 3, where the complete configuration is shown and the individual components are identified. The engine nacelles were hollow-contoured pipes that allowed unobstructed airflow through them.

Except for the portion of the test during which the effects of free transition were investigated, the tests were conducted with transition strips consisting of 0.0038-in.-diam glass spheres applied with an adhesive. The locations of the leading edge of the transition strips were as follow:

Model Component	Distance Aft of Leading Edge
Fuselage	2 in. aft of nose
Wing	10-percent chord
Vertical stabilizer	10-percent chord
Horizontal stabilizer	10-percent chord
Bullet	10-percent length
Pylons	10-percent chord
Nacelles	10-percent length

All transition strips were 0.05 in. wide, except that on the fuselage, which was 0.10 in. wide. A photograph of the wing transition strip is presented in Fig. 4.

During the portion of the test in which the empennage assembly was attached to the model, the horizontal stabilizer incidence angle was set at -1 deg (trailing edge up).

2.3 INSTRUMENTATION

A six-component, internal strain-gage balance was used to measure forces and moments of the entire model during the investigation. Pressures in the model cavity were measured at two locations by differential pressure transducers. The model gravimetric angle of attack was measured by a strain-gaged pendulum located forward of the balance in the model cavity.

SECTION III
TEST CONDITIONS AND PROCEDURE

3.1 GENERAL

The test was conducted at Mach numbers of 0.700, 0.767, and 0.785 at Reynolds numbers of 2.1, 2.8, and 4.2 million based on the wing mean aerodynamic chord. The total pressure ranged from 1645 psf at M_∞ = 0.785 and Re = 2.1 million to 3545 psf at M_∞ = 0.700 and Re = 4.2 million. The total temperature was maintained at 105°F for all Mach numbers.

Tunnel conditions were held constant at each Mach number, while angle of attack was varied from -3 to +3 deg. Data were recorded at each selected angle of attack.

3.2 ACCURACY OF MEASUREMENTS

The uncertainties associated with the various tunnel conditions and aerodynamic coefficients presented in the report are listed below. The uncertainties in force and moment coefficients include errors associated with balance or flexure zero shifts and calibration curve fits and are given for M_∞ = 0.767, Re = 2.8 x 10^6.

M_∞	=	±0.003
q_∞	=	±2 psf
α	=	±0.03 deg
T_t	=	±3°F
C_L	=	±0.004
C_m	=	±0.001
C_D	=	±0.0006

3.3 CORRECTIONS

Tests were conducted with the model both upright and inverted to define flow angularity in the vicinity of the model. The results of these tests, presented in Fig. 5, indicate the existence of a positive (upflow) flow angle which varied primarily with Reynolds number and to a lesser extent, with Mach number and model configuration. Angle of attack was corrected for the flow angle, and the coefficient data were computed with the corrected model angle.

The axial-force contribution to the lift, drag, and pitching-moment coefficients was computed with the model base pressure corrected to the value of free-stream static pressure. The difference $(p_\infty - p_b)$ varied from $-0.023\ q_\infty$ at $M_\infty = 0.700$ and $Re = 2.1 \times 10^6$ to $-0.047\ q_\infty$ at $M_\infty = 0.785$ and $Re = 4.2 \times 10^6$.

SECTION IV
RESULTS AND DISCUSSION

The measured aerodynamic characteristics are presented in stability axis coefficient form in Figs. 6 through 12, showing the effects of Reynolds number variation from 2.1×10^6 to 4.2×10^6 for both free and fixed transition.

The effects of Reynolds number variation on the lift and pitching-moment coefficients presented in Figs. 6 through 9 show that the greatest effect occurred for the fixed transition configuration with empennage, pylons, and nacelles off, where at $M_\infty > 0.700$ and $\alpha > 0$ deg, C_L increased (Fig. 6) and C_m became more negative at $Re = 2.1 \times 10^6$ (Fig. 8).

The most pronounced effect of Reynolds number variation is noted in the drag coefficients, as may be seen in Figs. 10, 11, and 12. The forebody drag coefficients decreased with increasing Reynolds number at all values of C_L, except at $M_\infty = 0.785$ where, for the empennage, pylons, and nacelles-off configuration with fixed transition, C_{D_F} at $Re = 2.8 \times 10^6$ is larger than that for $Re = 2.1 \times 10^6$ for $C_L > 0.475$. An increase in C_{D_F} at $M_\infty = 0.785$ with increasing Reynolds number may also be noted for the complete model with fixed transition for $C_L > 0.55$. As shown in Fig. 12, the forebody drag coefficients showed essentially a linear decrease with increasing Reynolds number for both fixed and free transition.

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5. Chevalier, H. L. "Calibration of the PWT 16-Foot Transonic Circuit with a Modified Model Support System and Test Section." AEDC-TN-60-164, August 1960.

APPENDIX
ILLUSTRATIONS

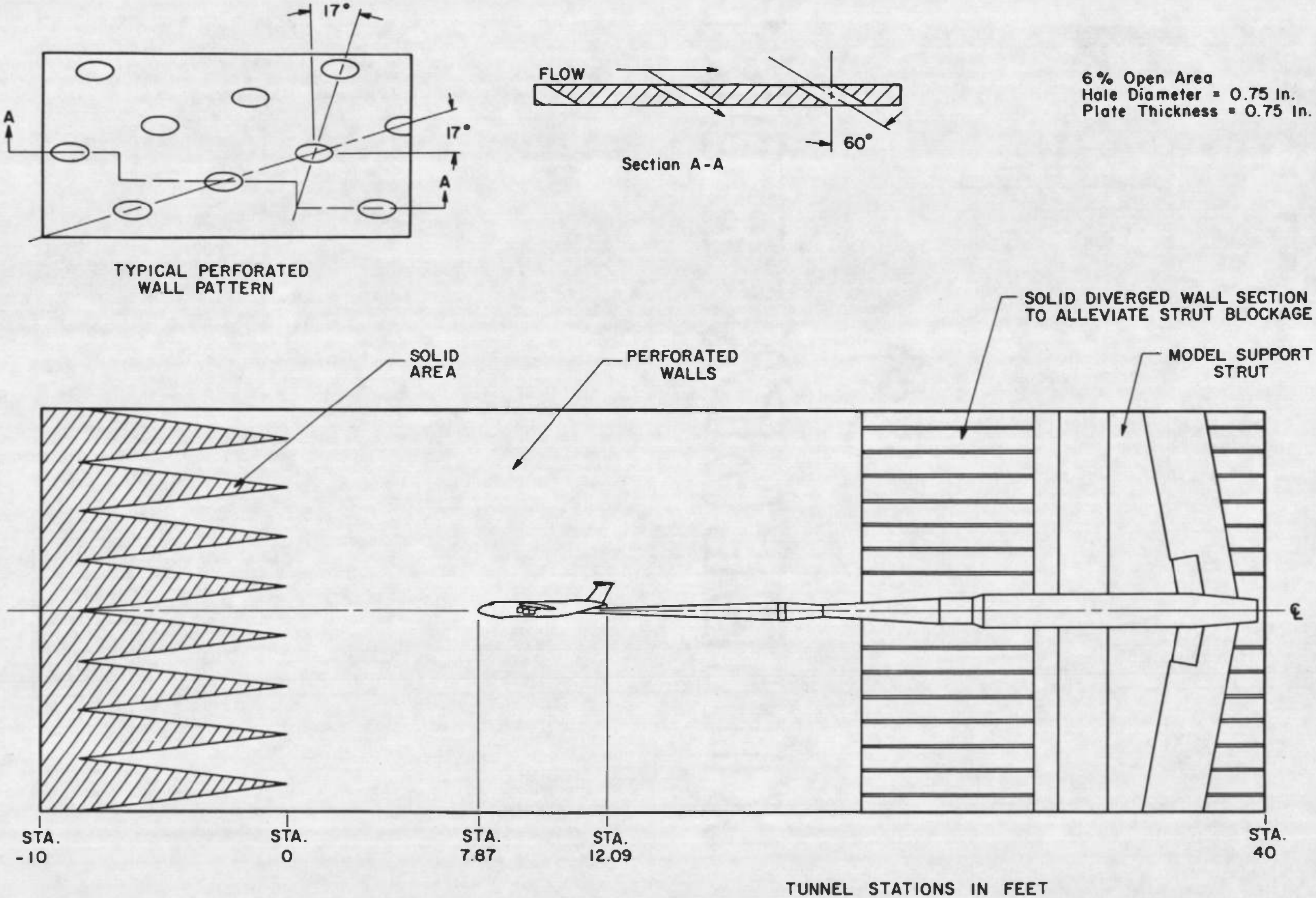


Fig. 1 Schematic of Model Installation

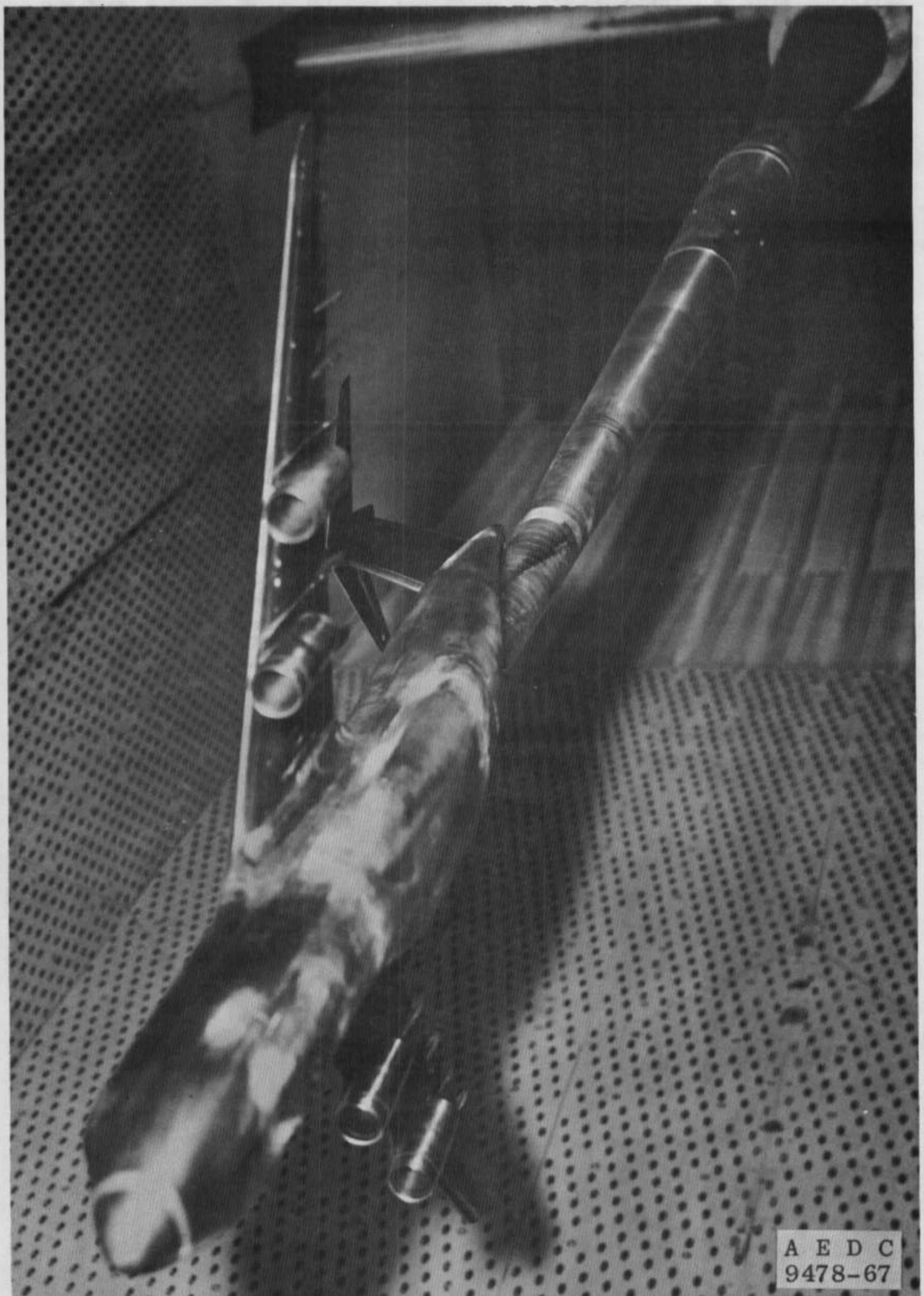
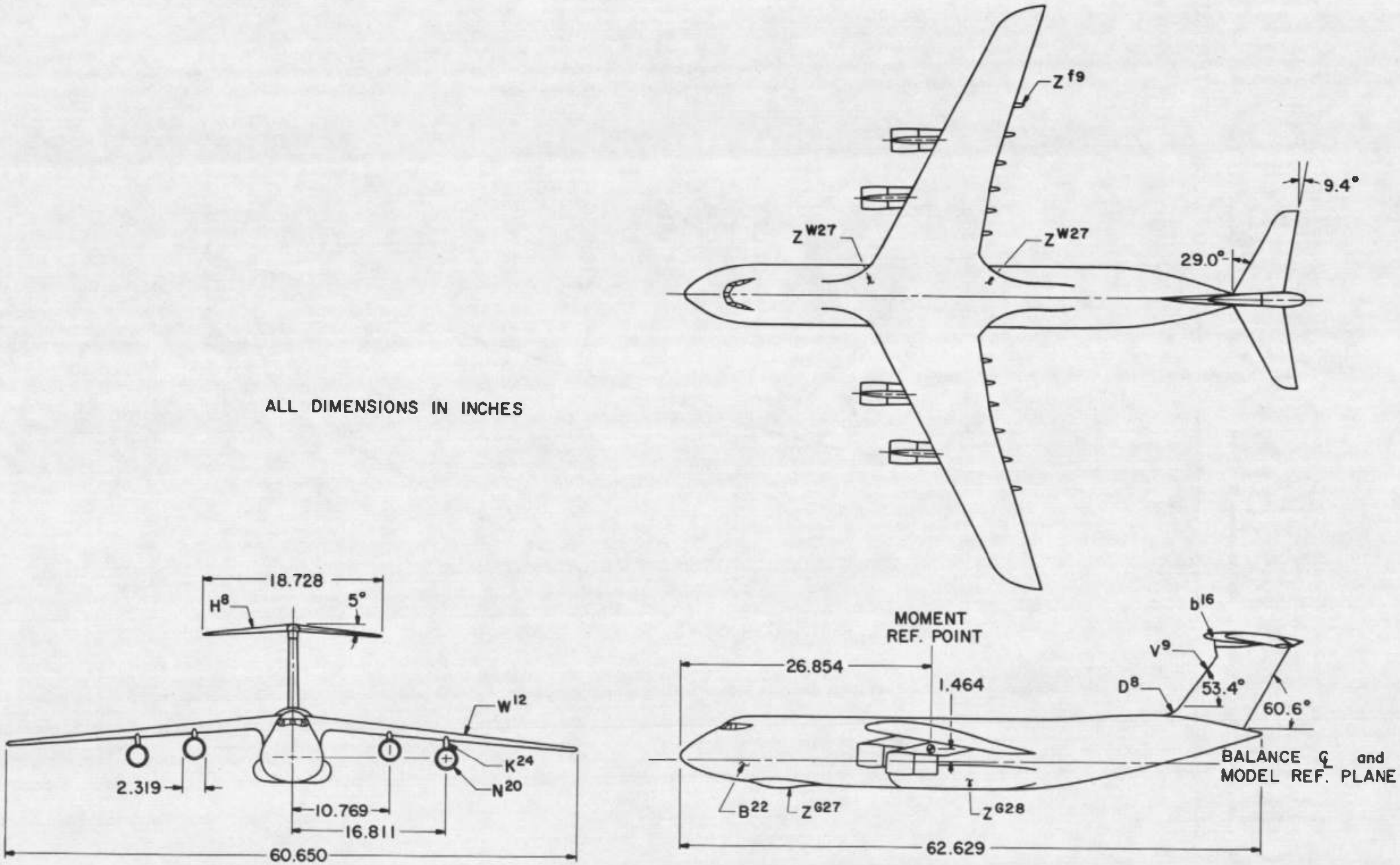
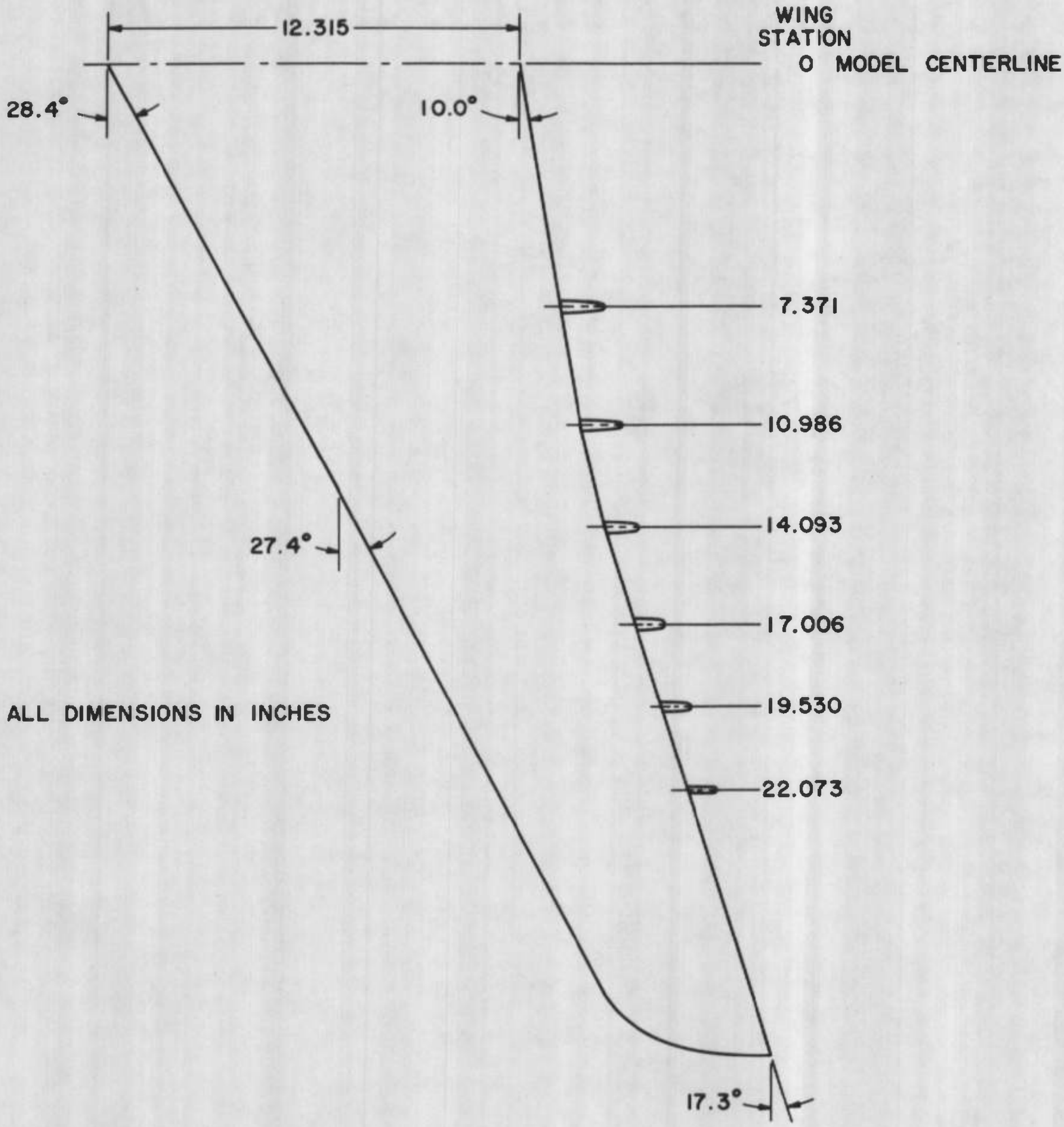


Fig. 2 Photograph of 0.0226-Scale Model of the C-5A Installed in Test Section



a. Complete Model

Fig. 3 Details and Dimensions of Model



b. Wing Details
Fig. 3 Concluded

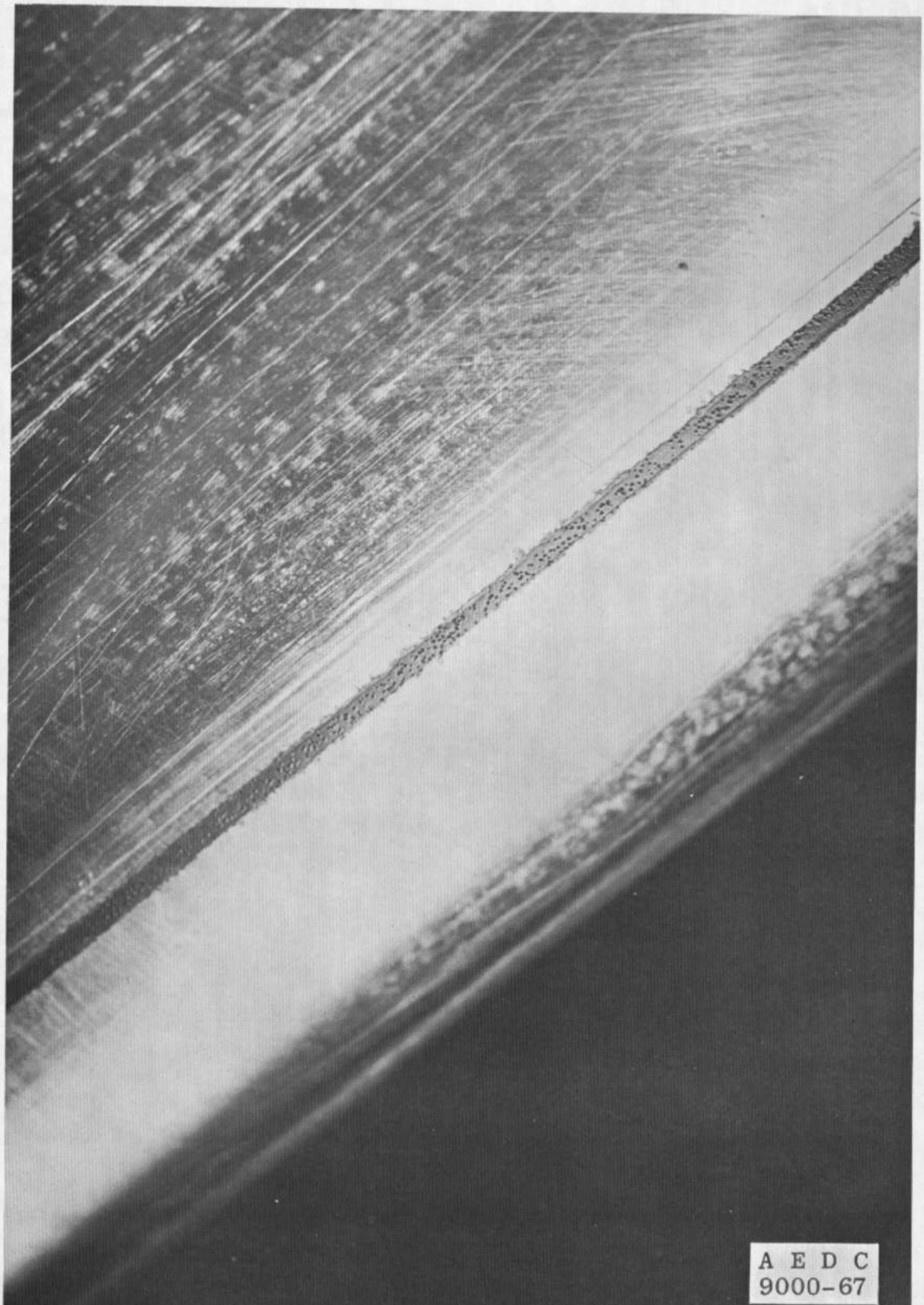
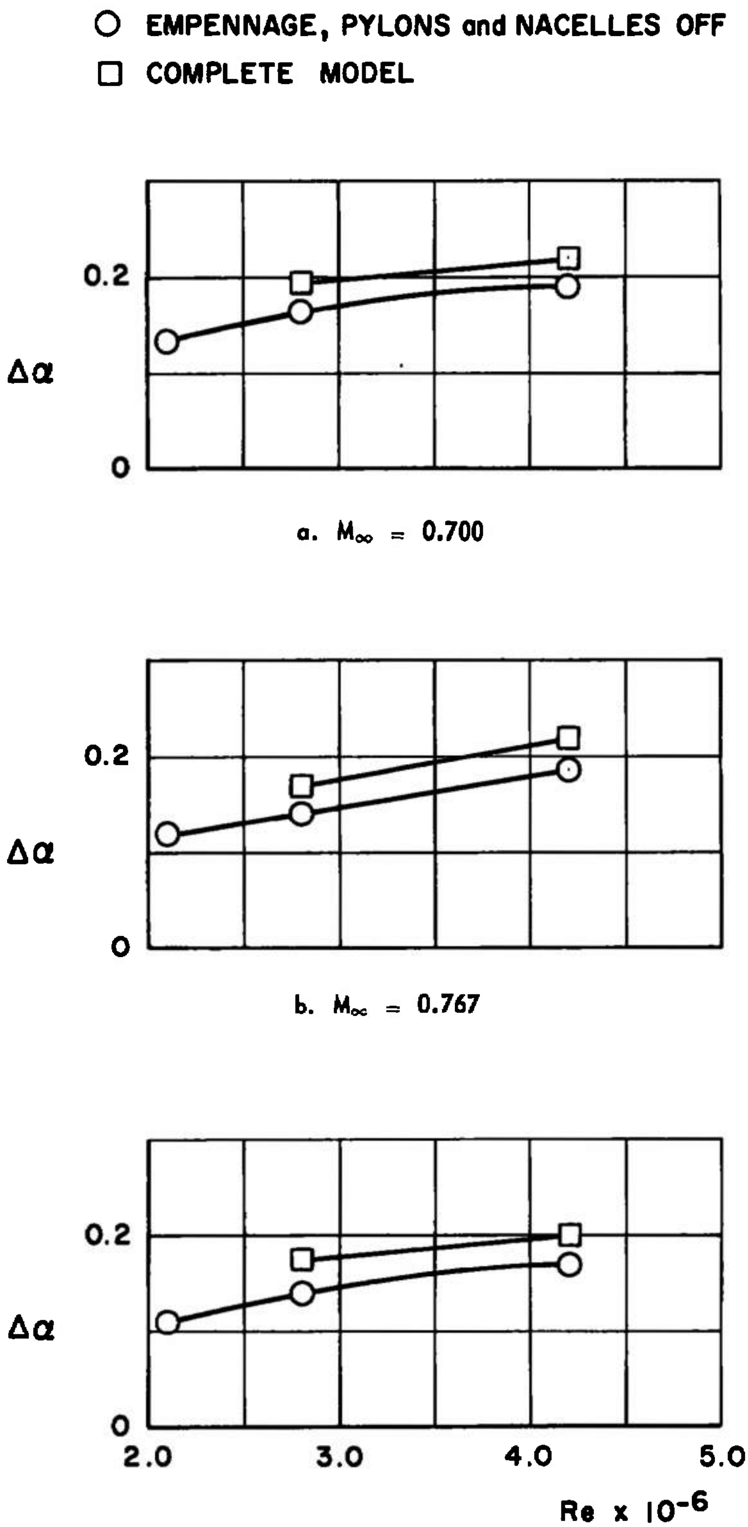
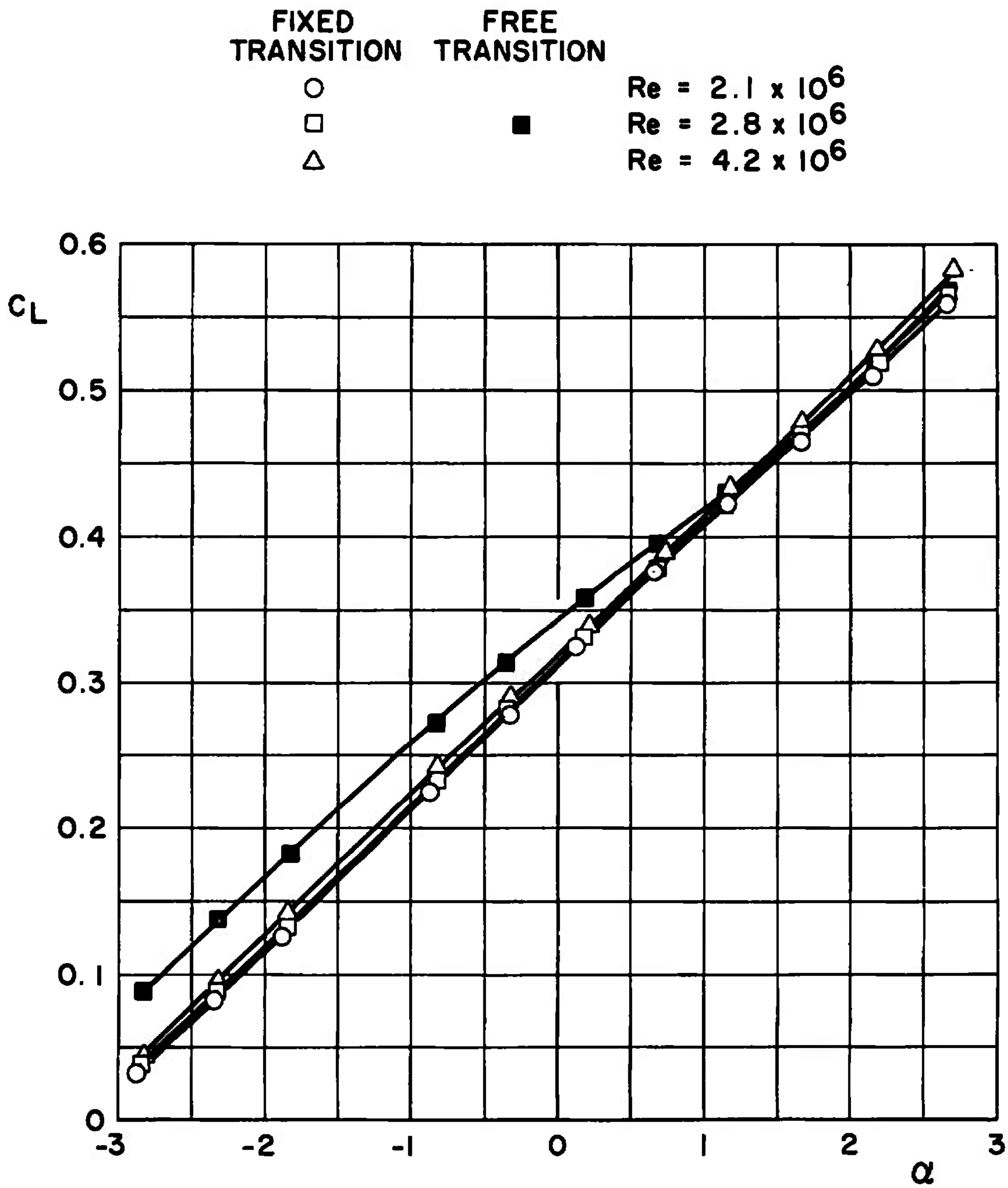


Fig. 4 Photograph of a Typical Transition Strip



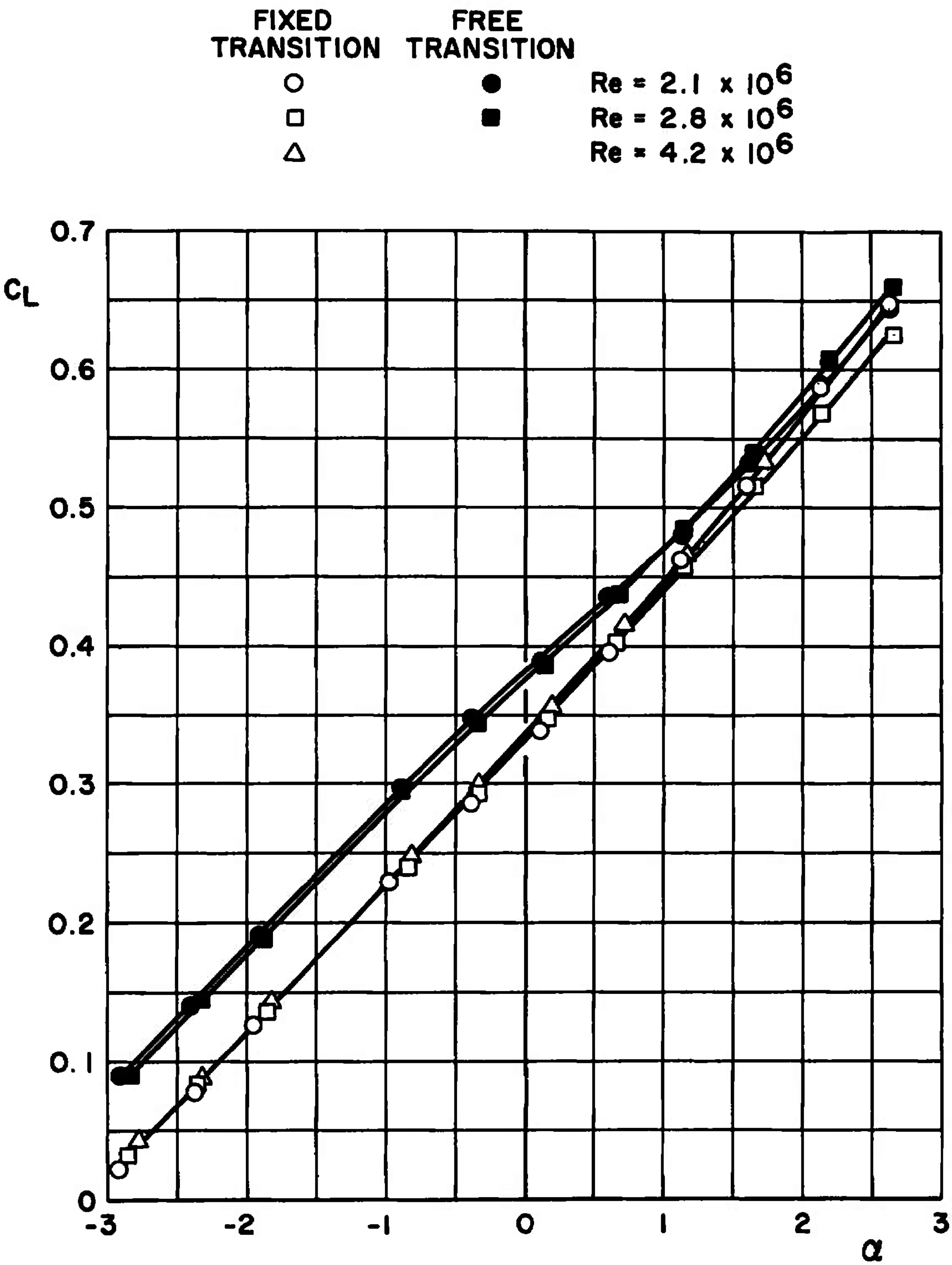
c. M_∞ = 0.785

Fig. 5 Variation of Tunnel Flow Angle with Reynolds Number



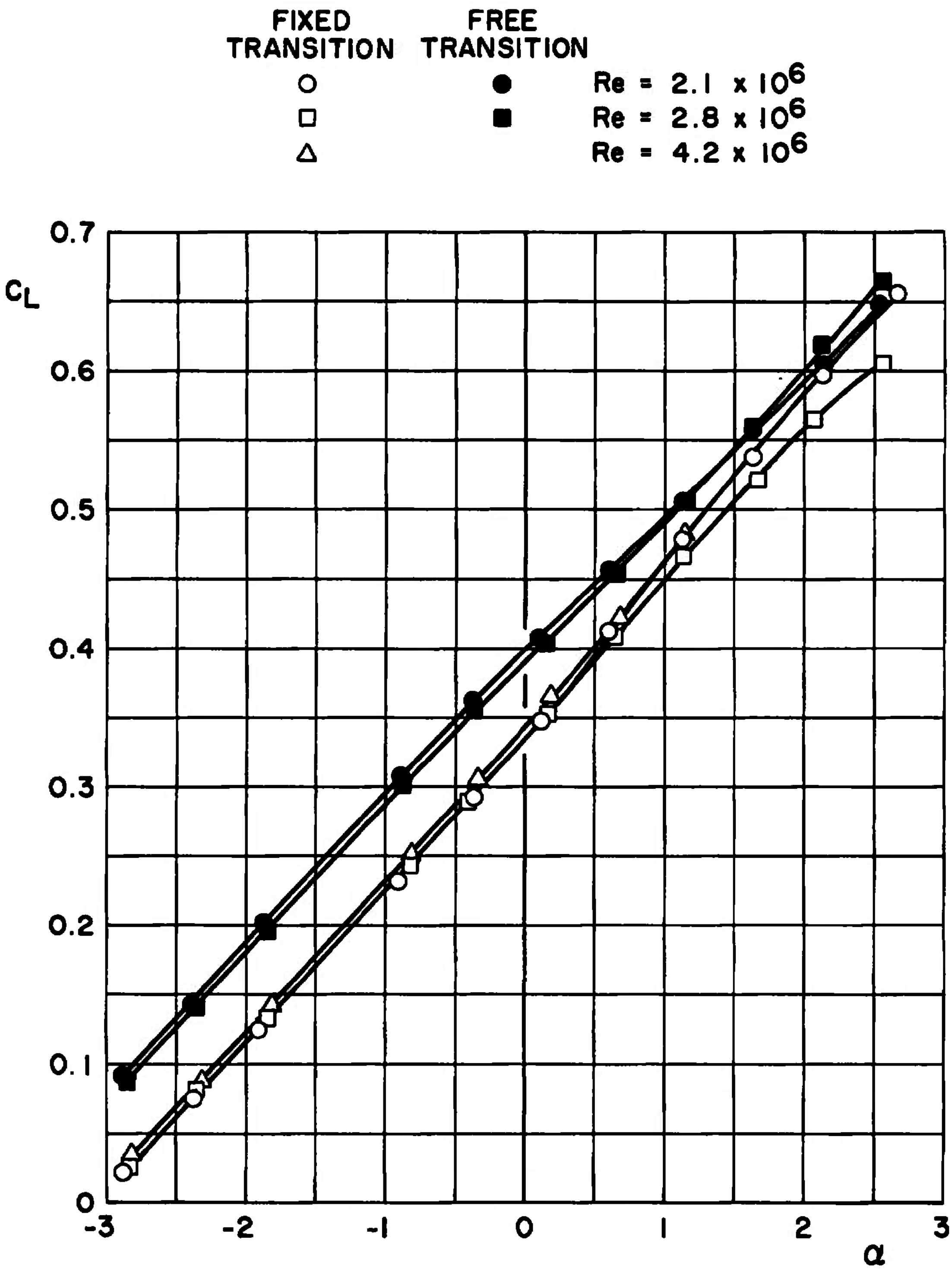
a. M_∞ = 0.700

Fig. 6 Effects of Reynolds Number Variation on Lift Coefficients for Fixed and Free Transition for the Configuration with Empennage, Pylons, and Nacelles Off



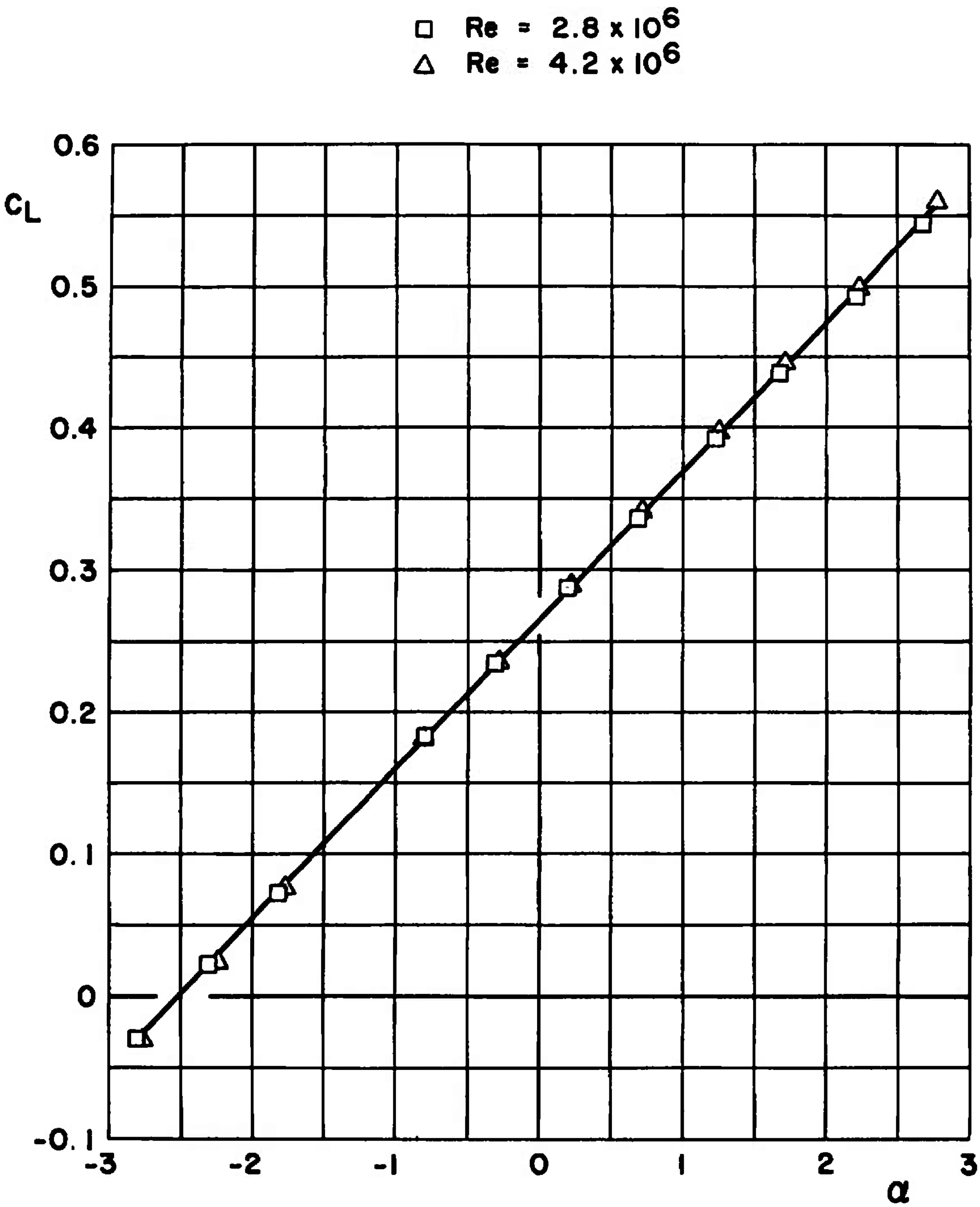
b. M_∞ = 0.767

Fig. 6 Continued



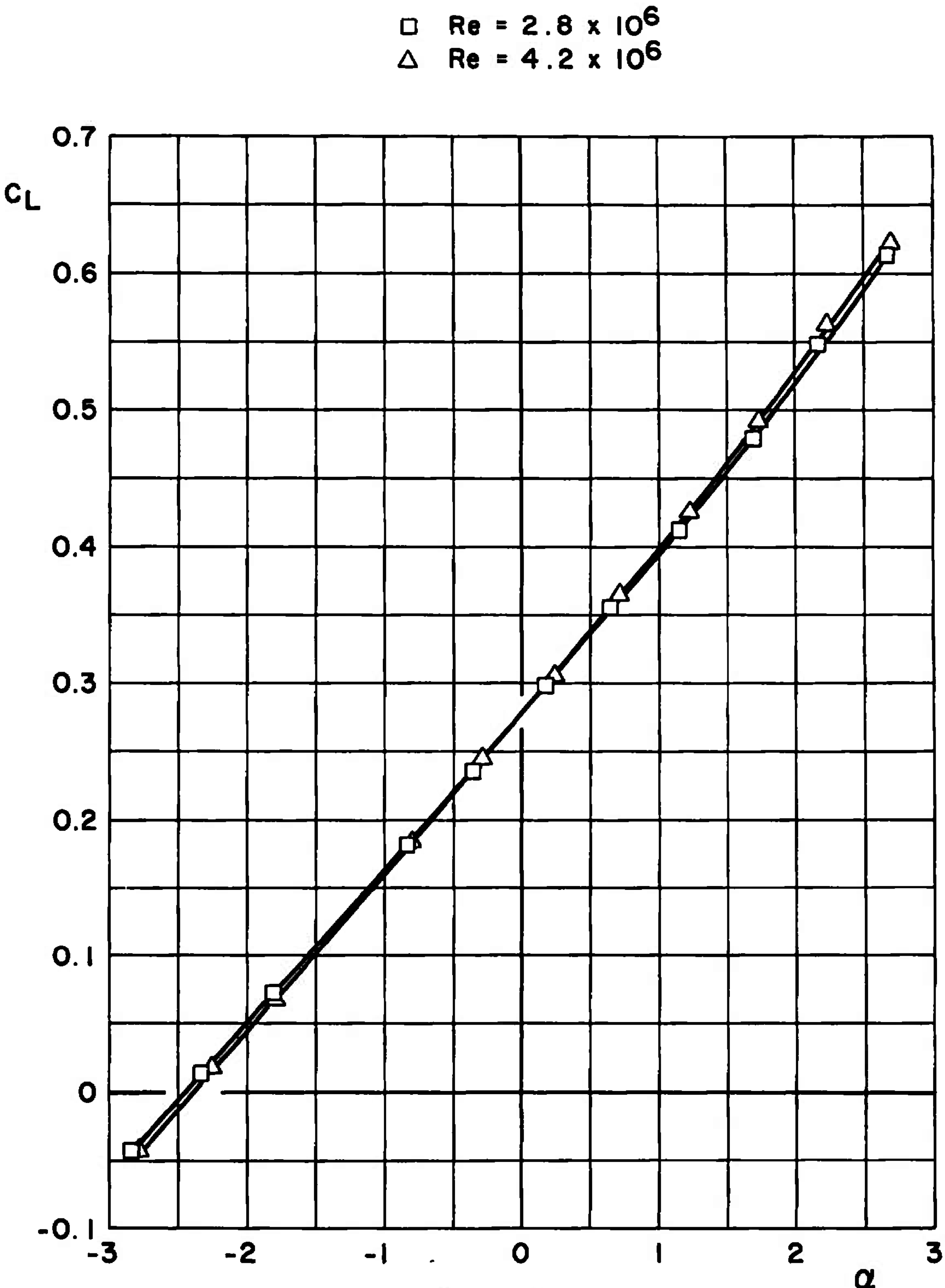
c. M_∞ = 0.785

Fig. 6 Concluded

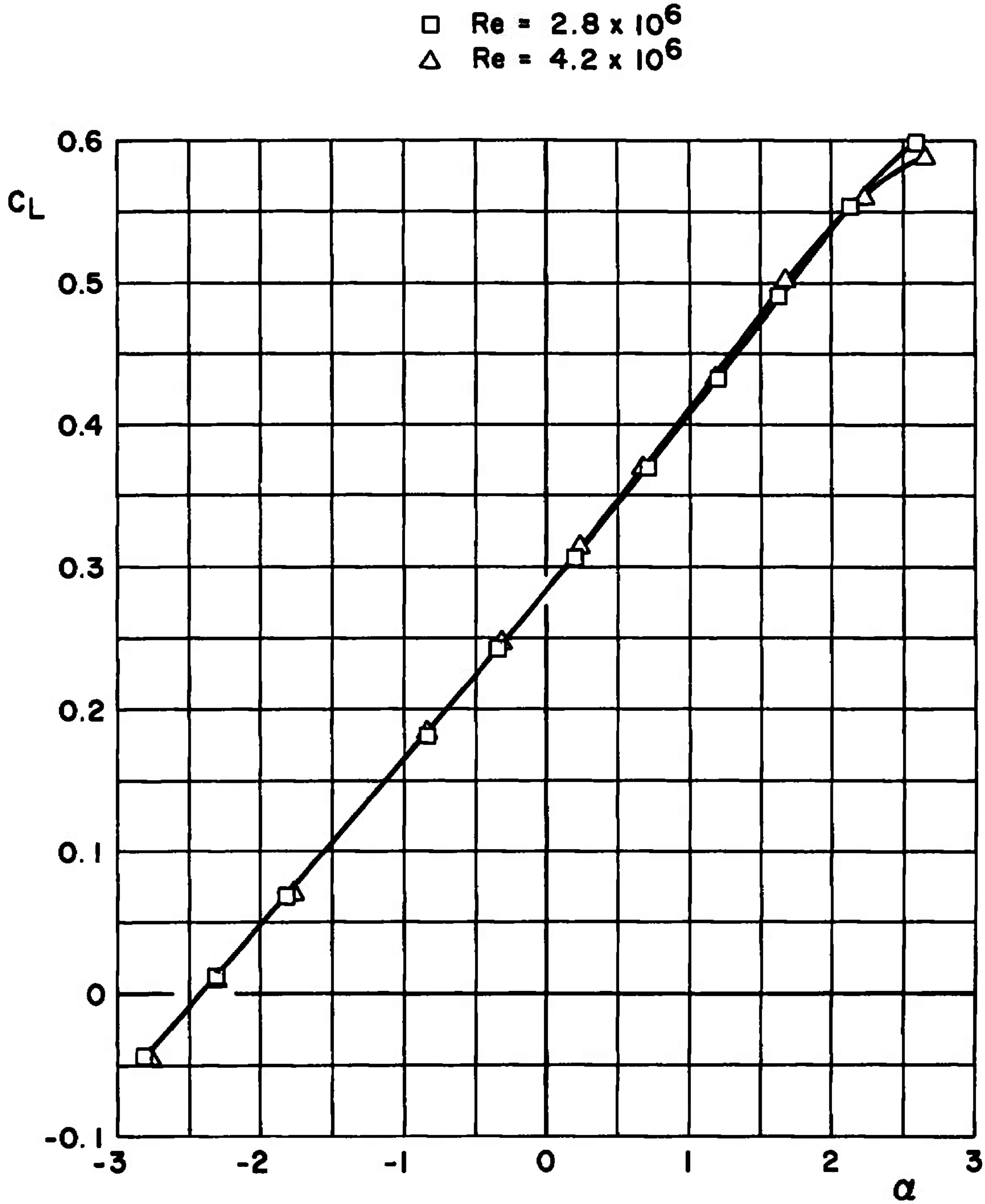


a. M_∞ = 0.700

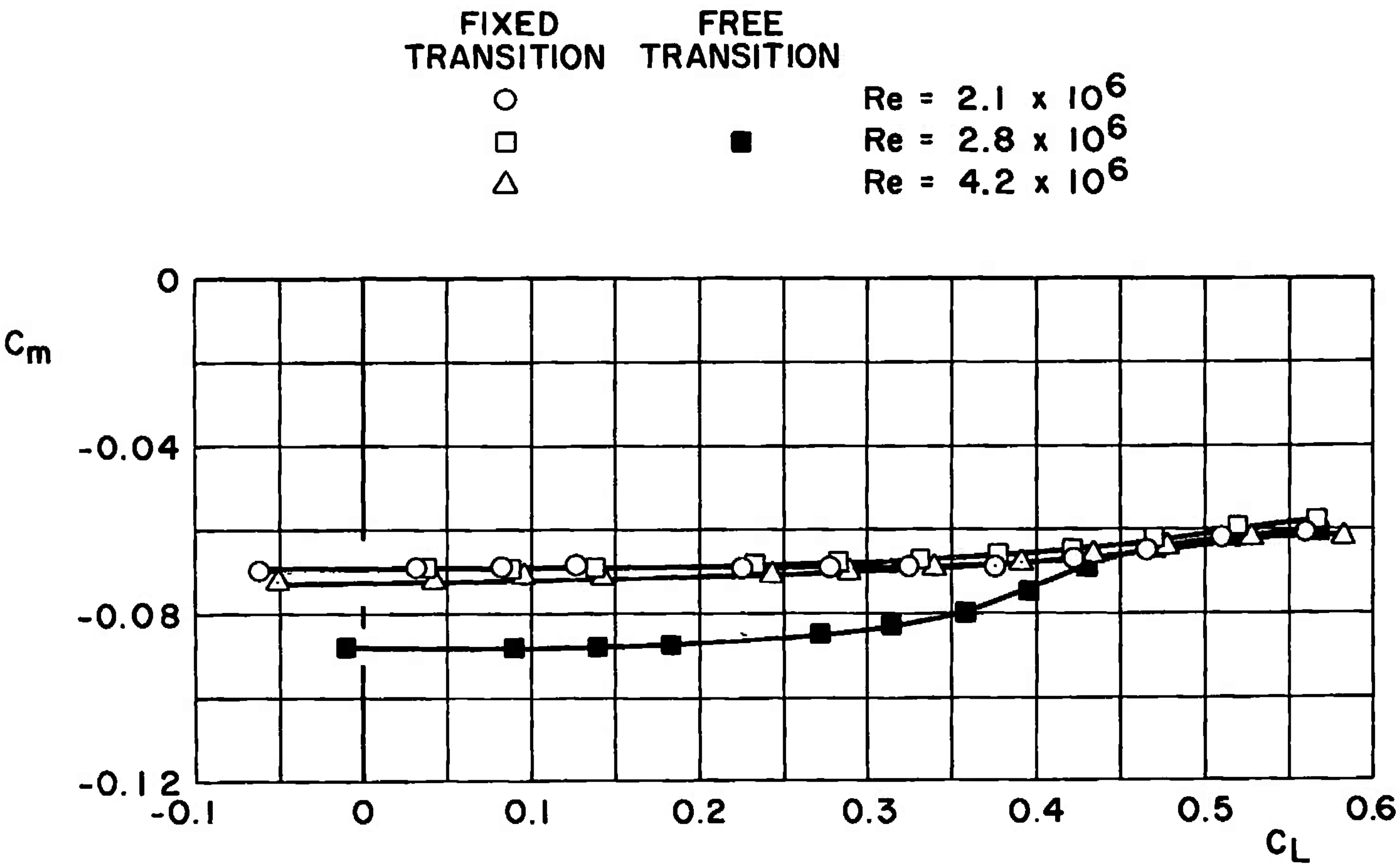
Fig. 7 Effects of Reynolds Number Variation on Lift Coefficients for the Complete Model, Fixed Transition



b. M_∞ = 0.767
Fig. 7 Continued

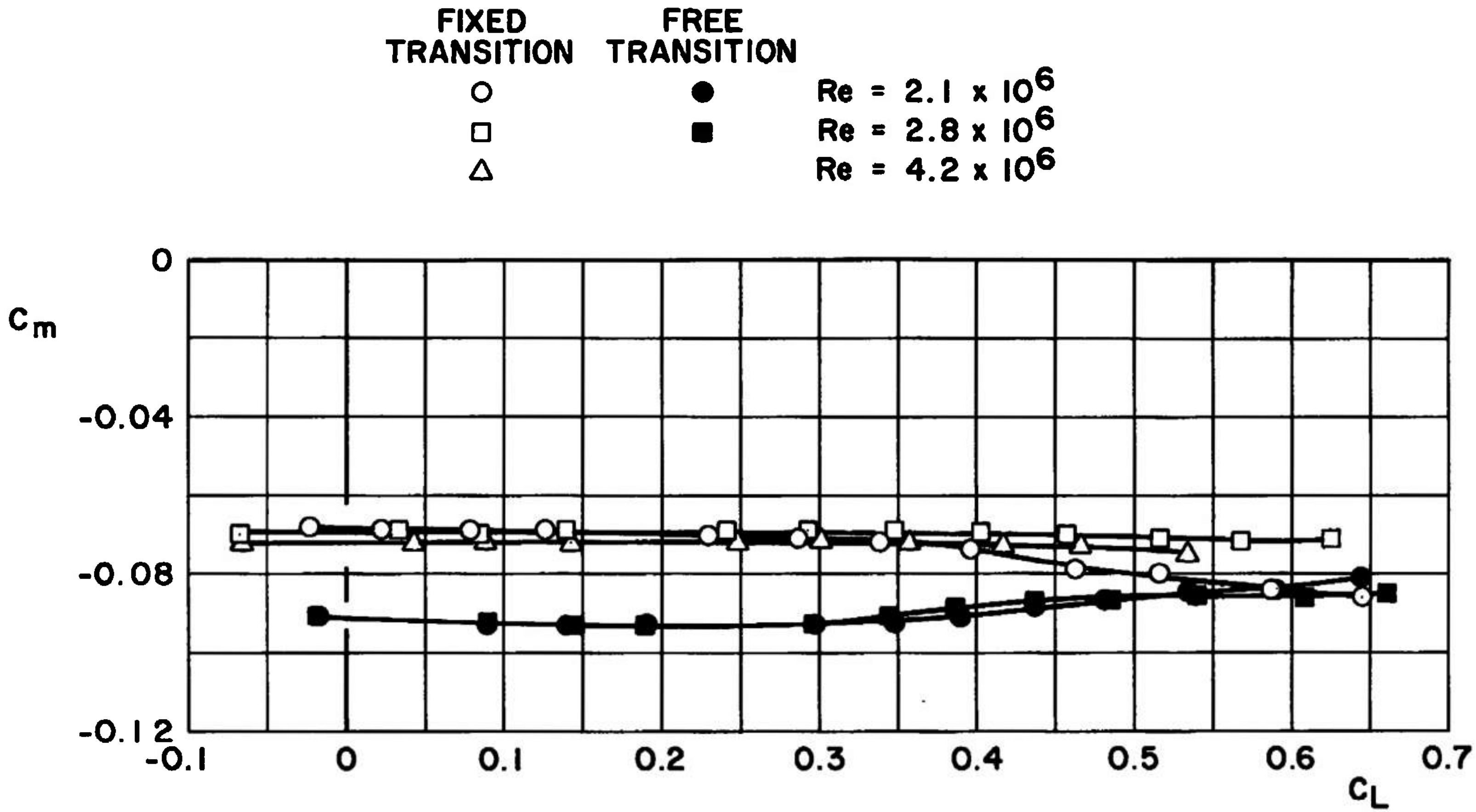


c. M_∞ = 0.785
Fig. 7 Concluded



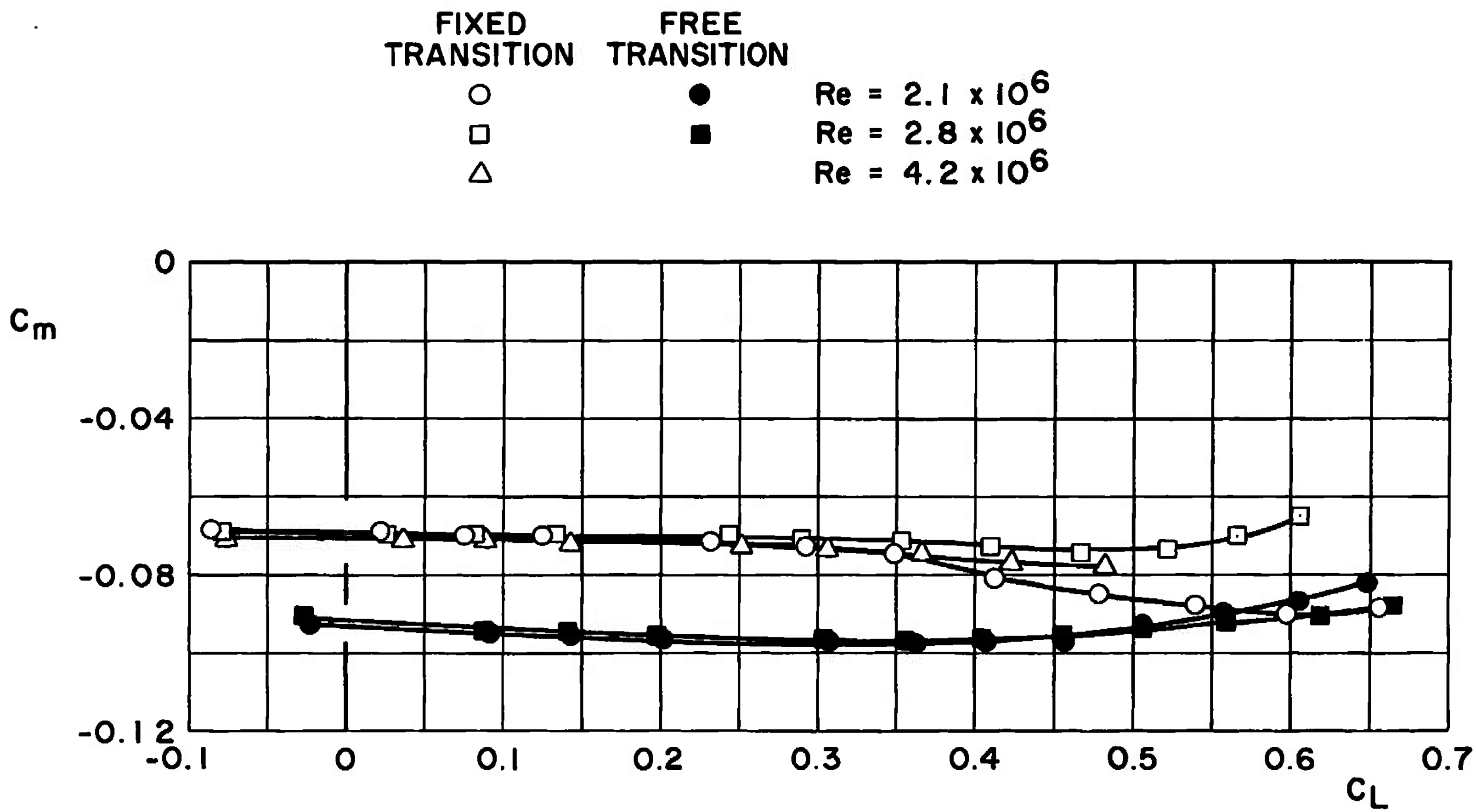
a. $M_\infty = 0.700$

Fig. 8 Effects of Reynolds Number Variation on Pitching-Moment Coefficients for Fixed and Free Transition for the Configuration with Empennage, Pylons, and Nacelles Off



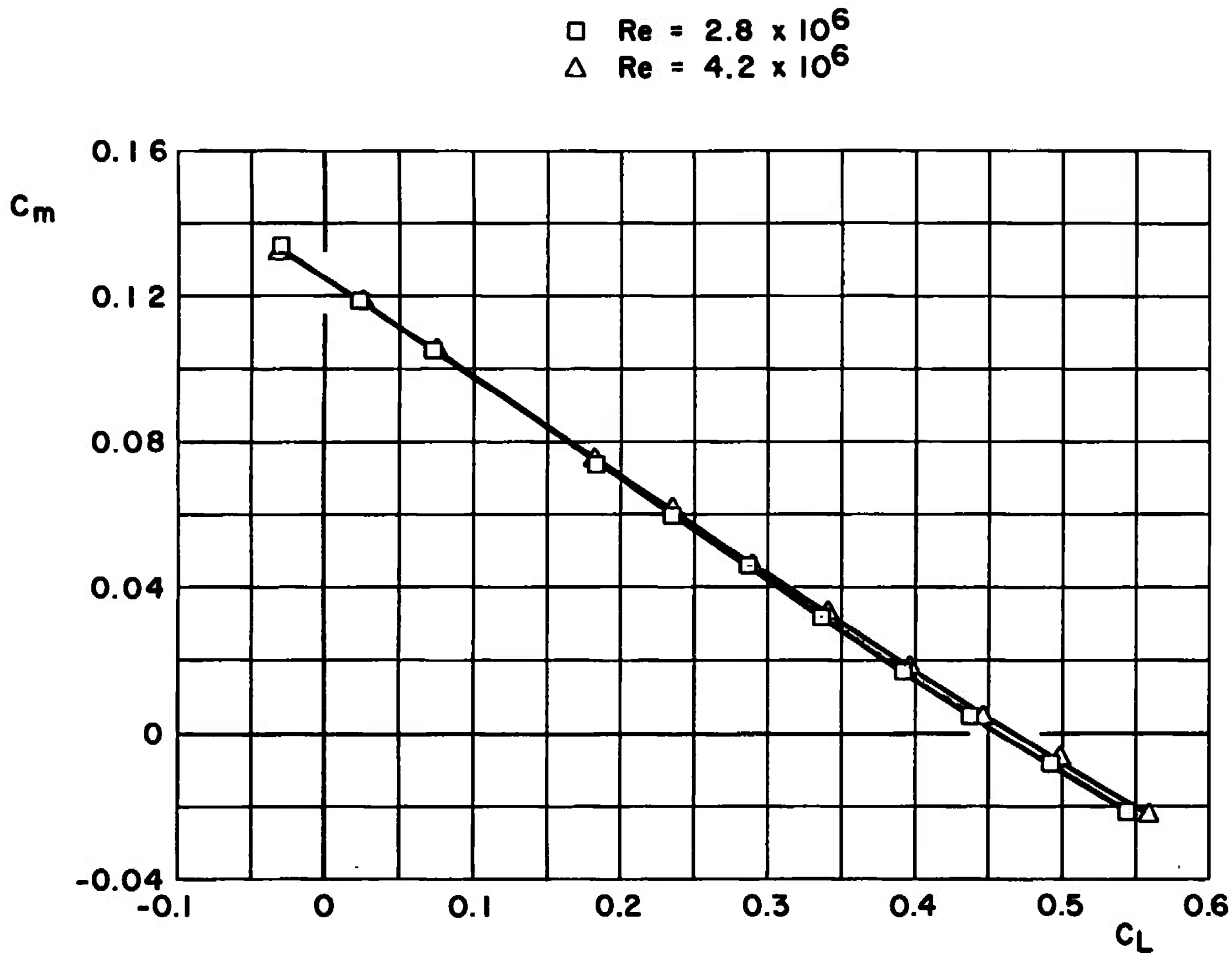
b. M_∞ = 0.767

Fig. 8 Continued



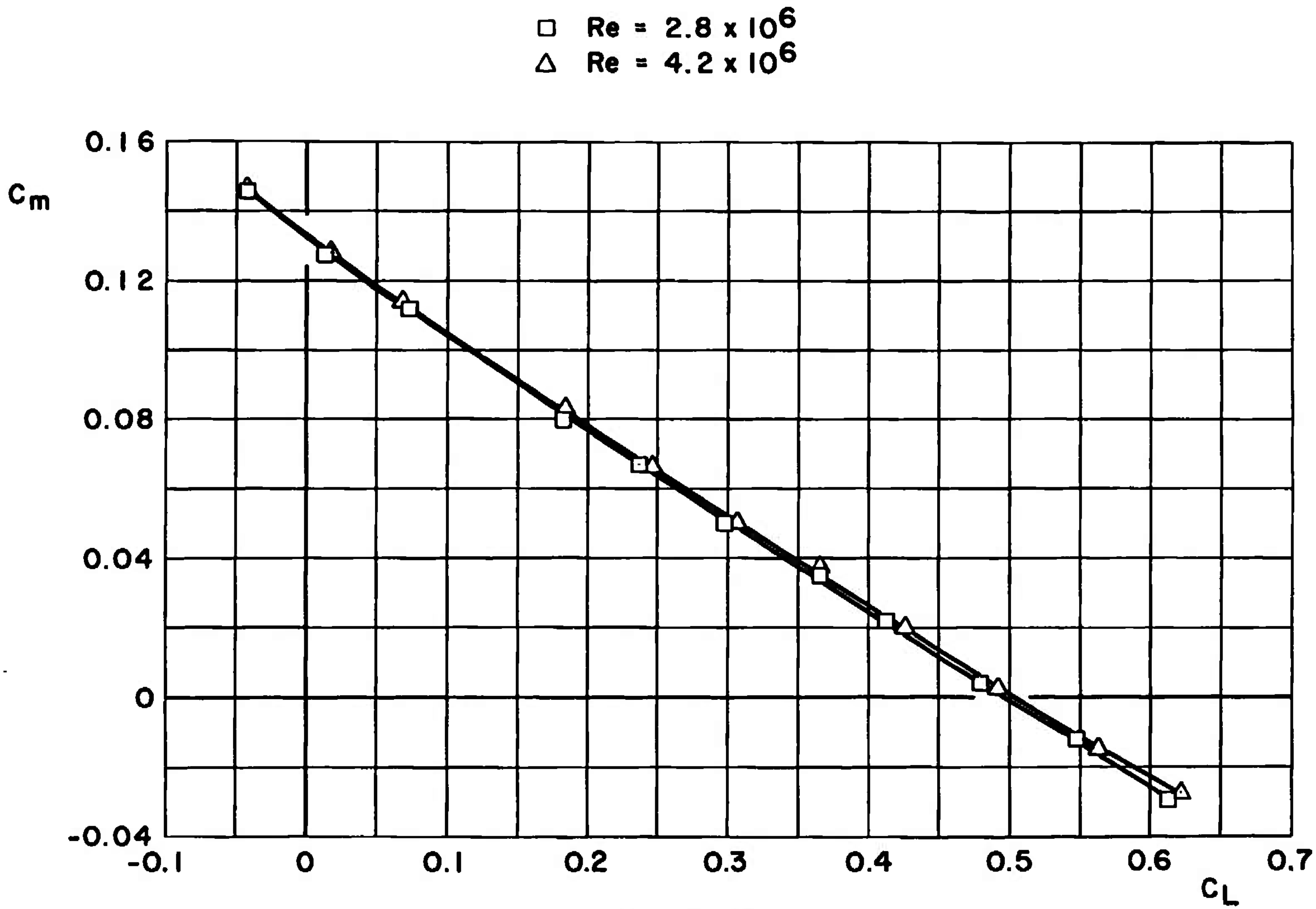
c. $M_\infty = 0.785$

Fig. 8 Concluded

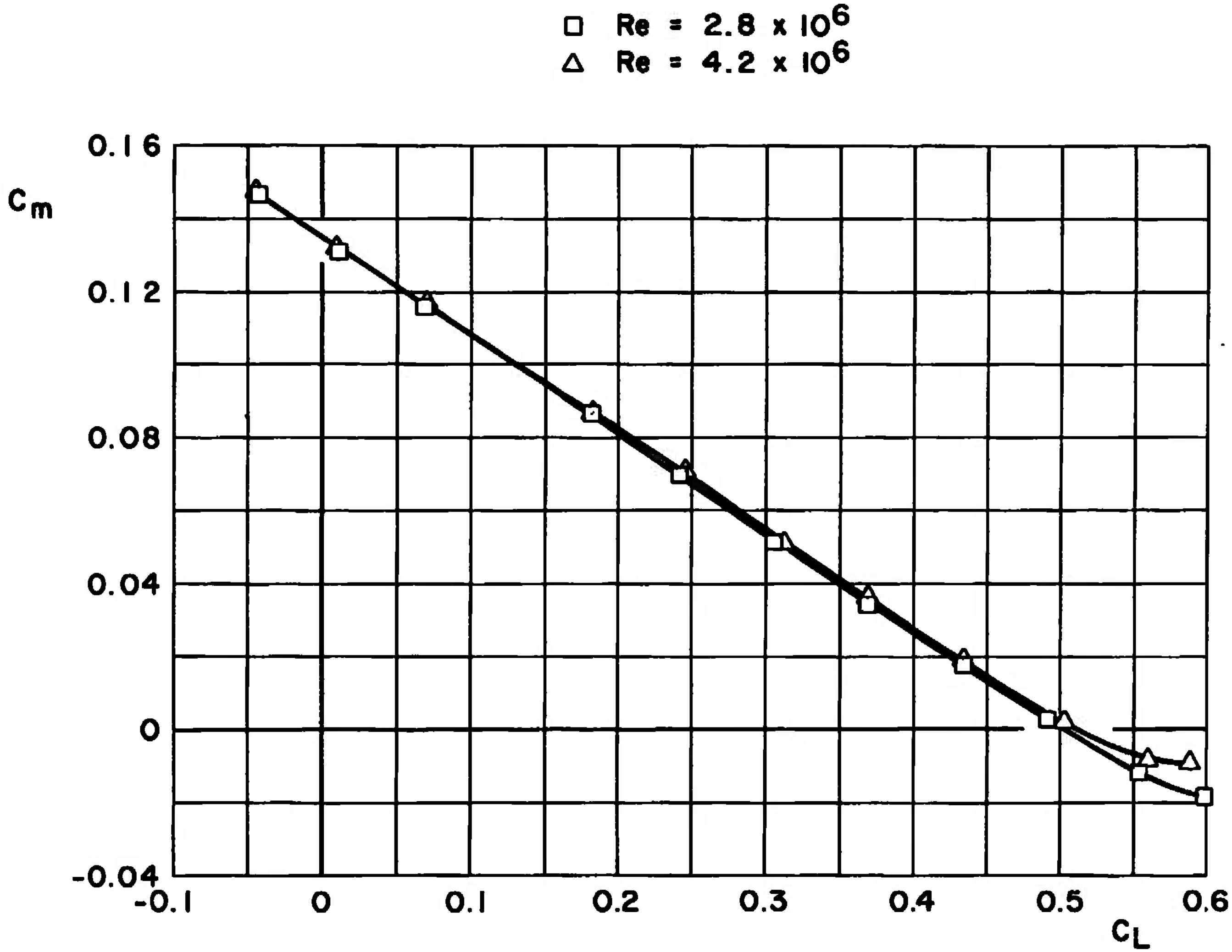


a. $M_\infty = 0.700$

Fig. 9 Effects of Reynolds Number Variation on Pitching-Moment Coefficients for the Complete Model, Fixed Transition

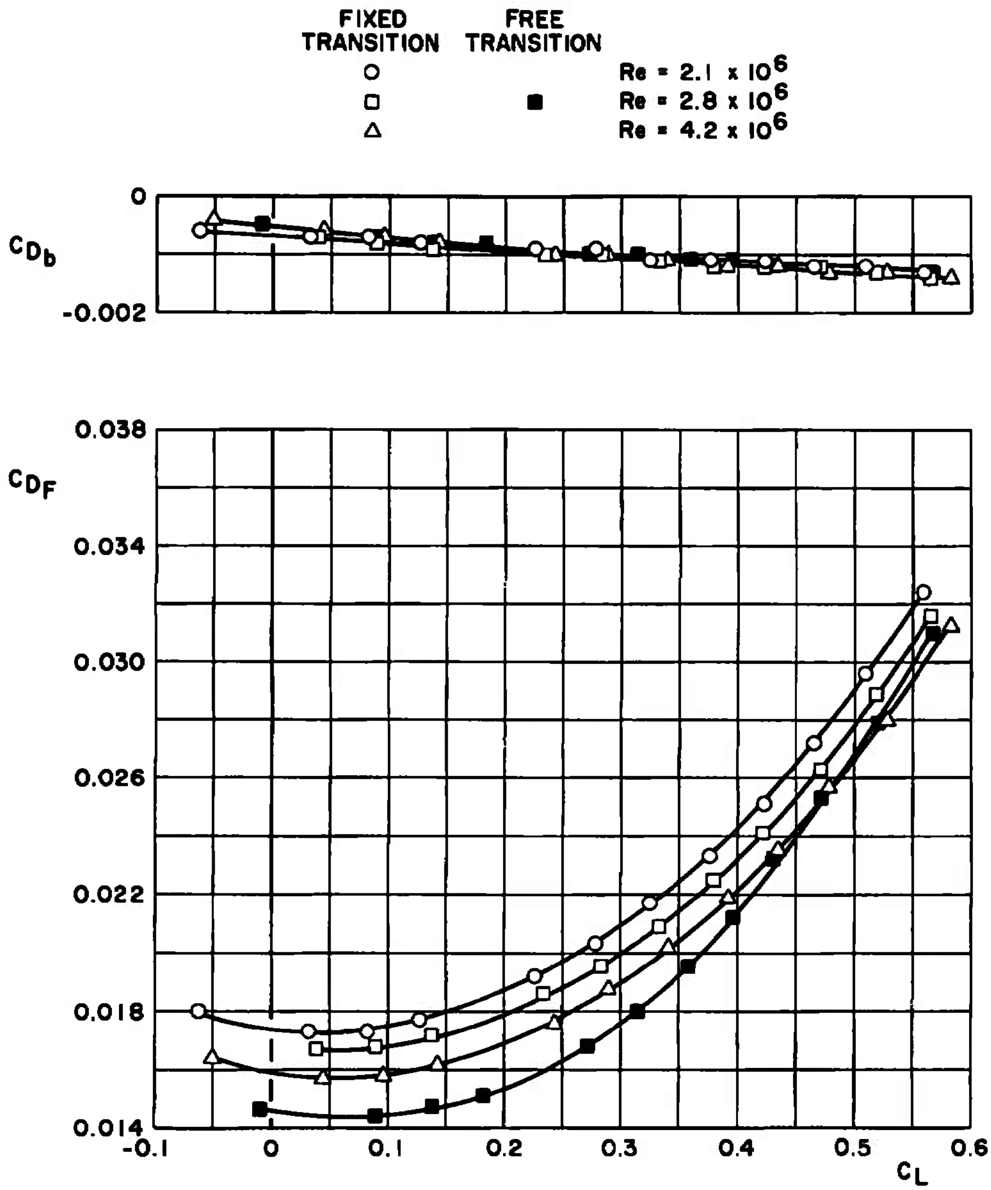


b. M_∞ = 0.767
Fig. 9 Continued



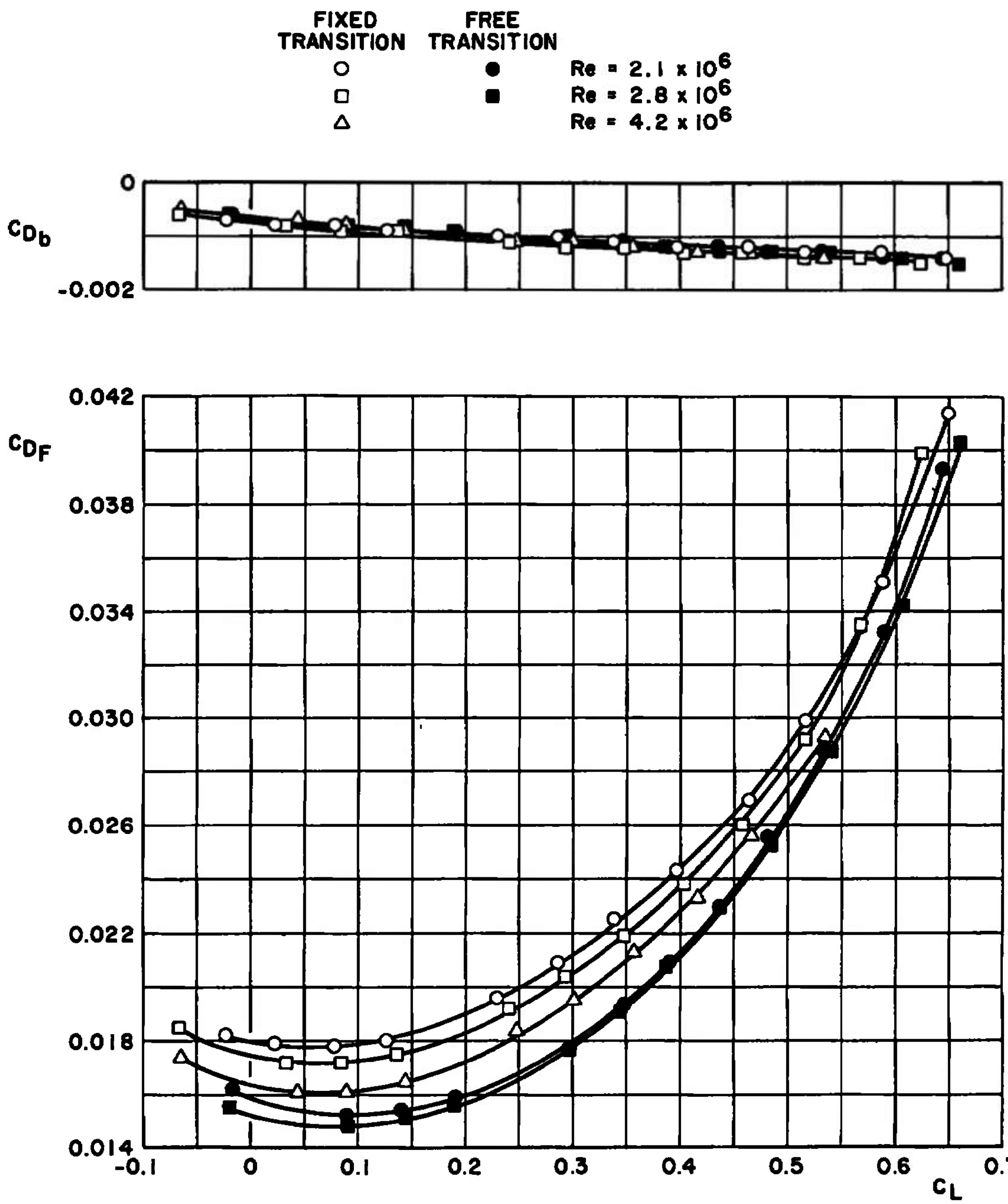
c. $M_\infty = 0.785$

Fig. 9 Concluded



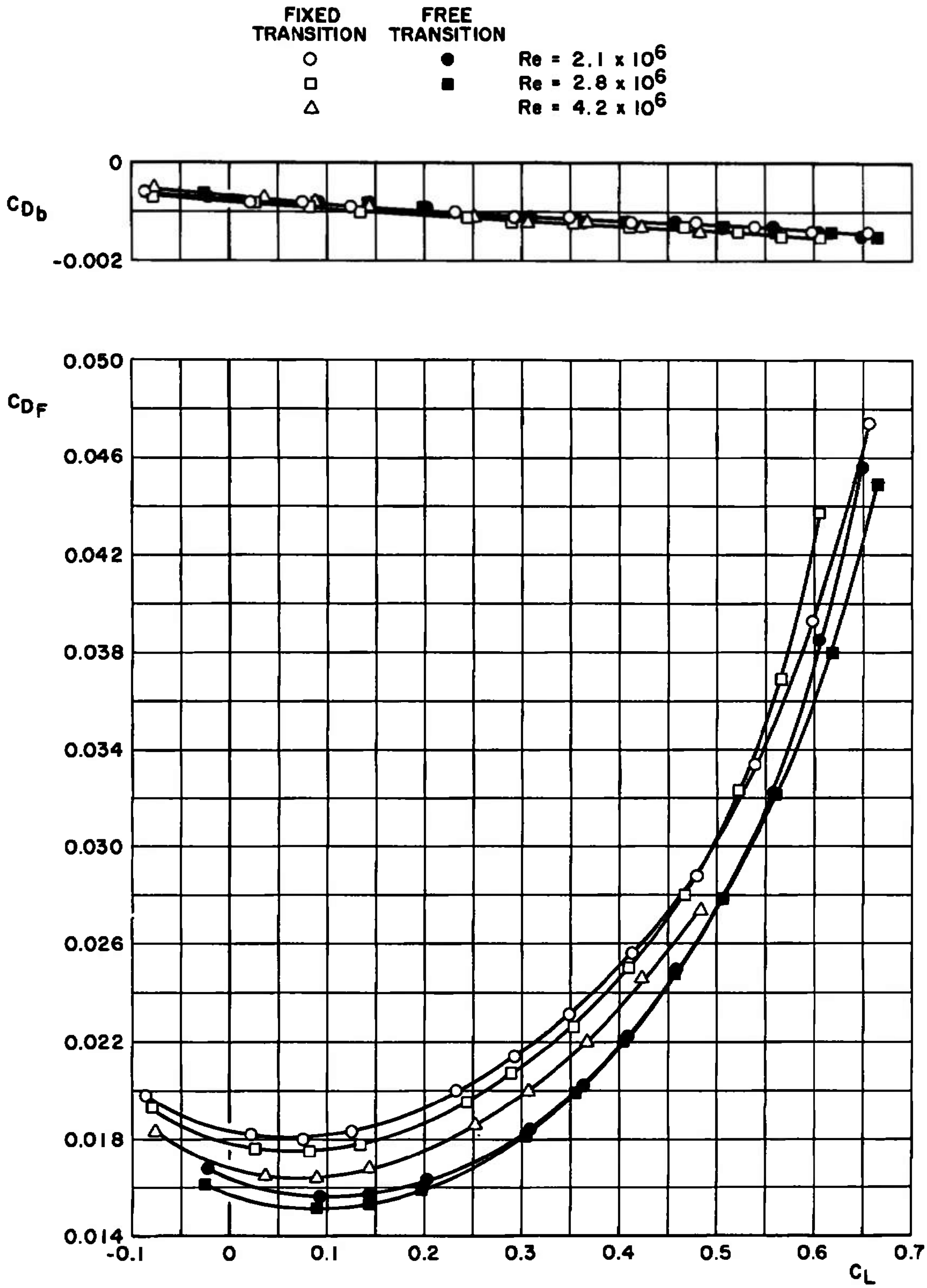
a. $M_\infty = 0.700$

Fig. 10 Effects of Reynolds Number Variation on Drag Coefficients for Fixed and Free Transition for the Configuration with Empennage, Pylons, and Nacelles Off



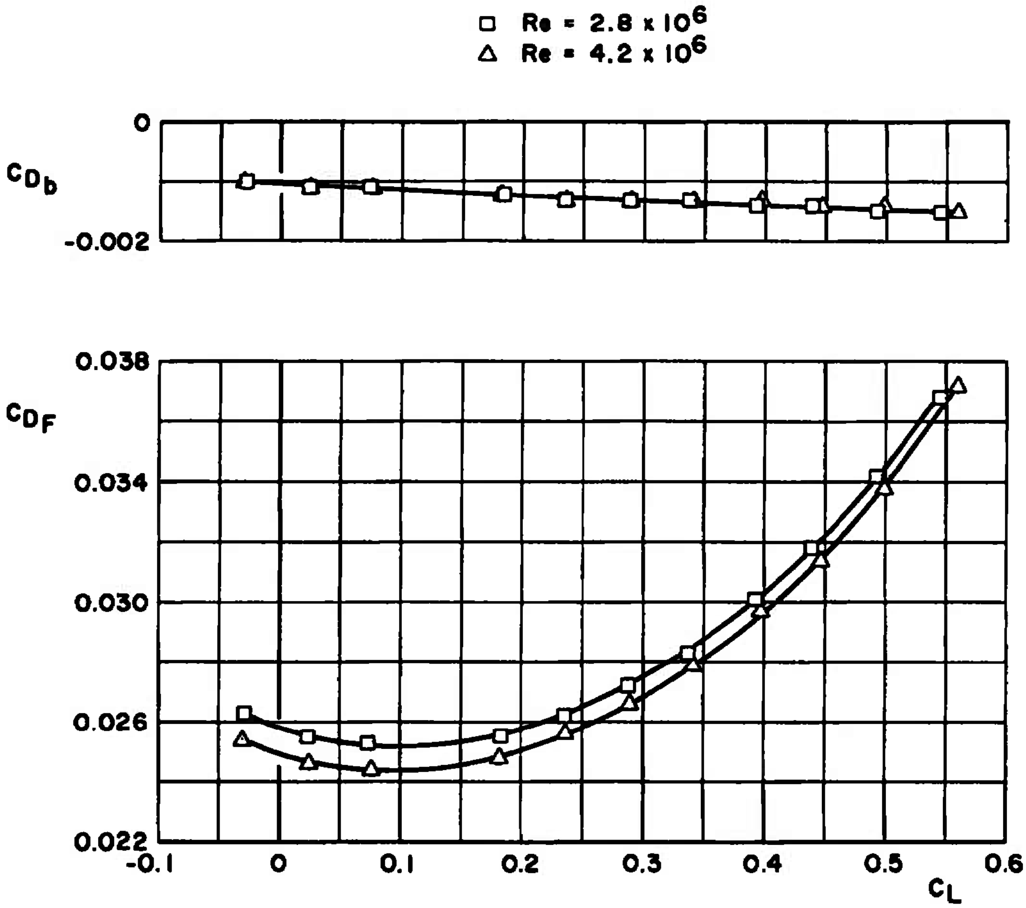
b. M_∞ = 0.767

Fig. 10 Continued



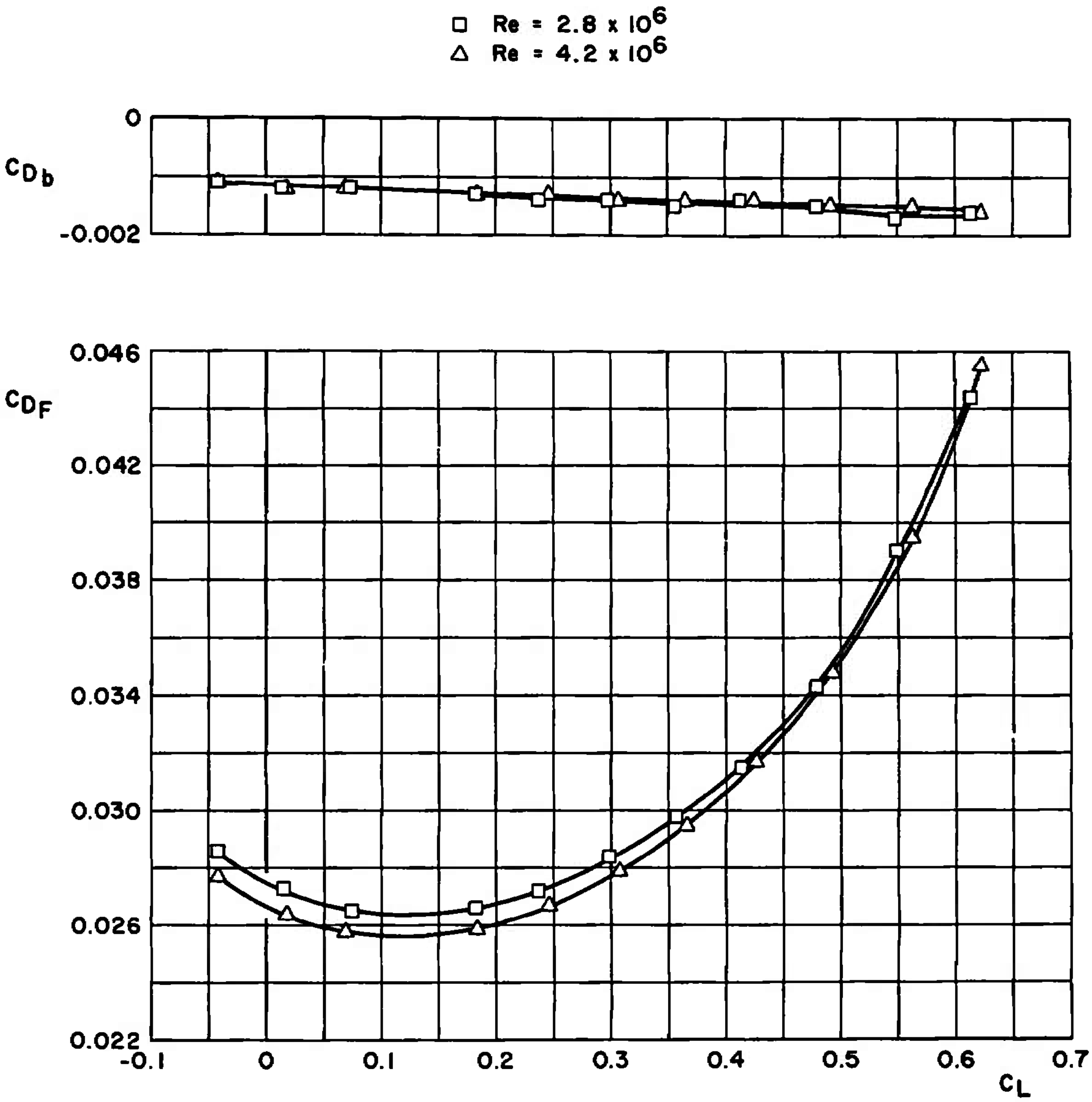
c. $M_\infty = 0.785$

Fig. 10 Concluded



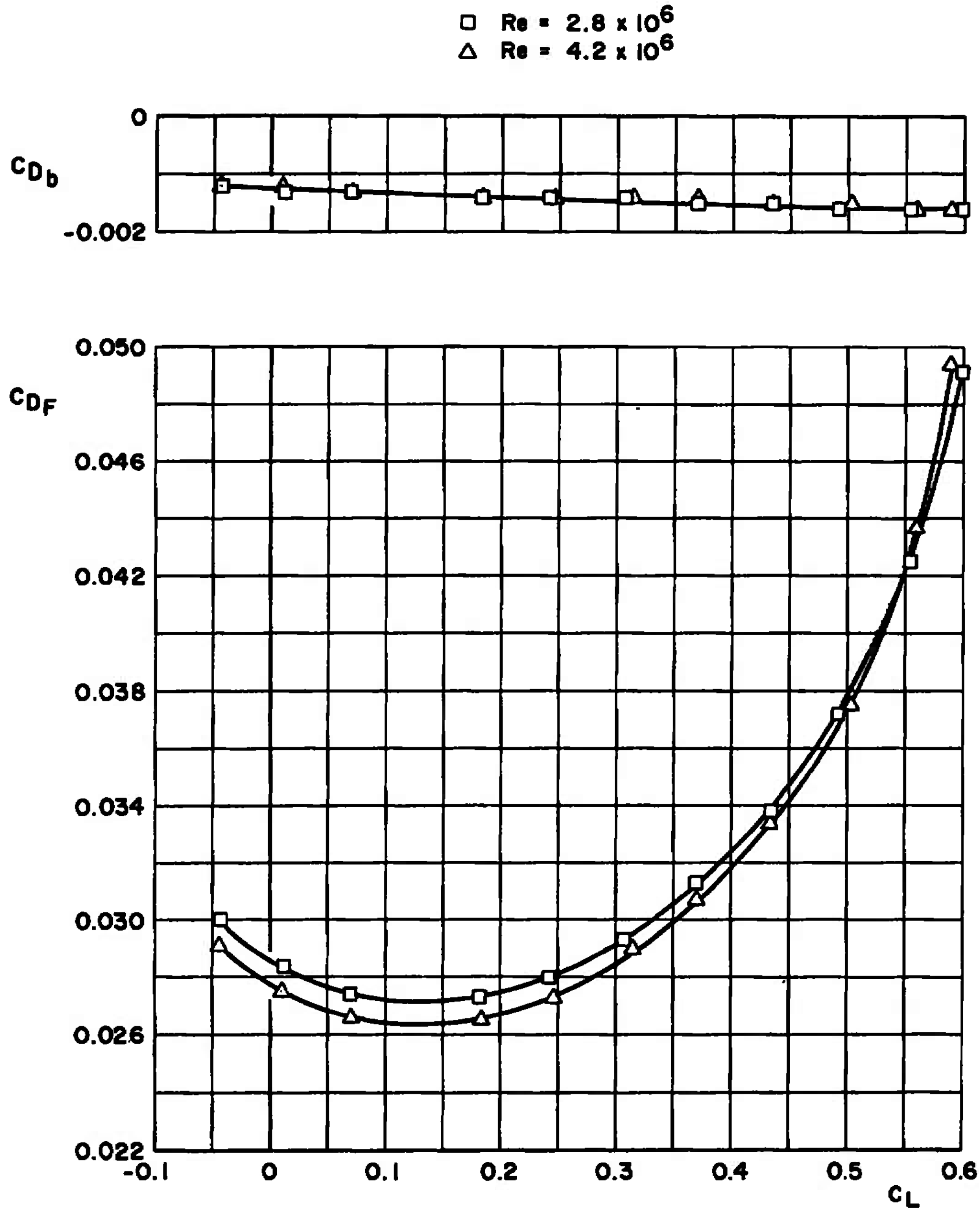
a. M_∞ = 0.700

Fig. 11 Effects of Reynolds Number Variation on Drag Coefficients for the Complete Model, Fixed Transition



b. M_∞ = 0.767

Fig. 11 Continued



c. M_∞ = 0.785

Fig. 11 Concluded

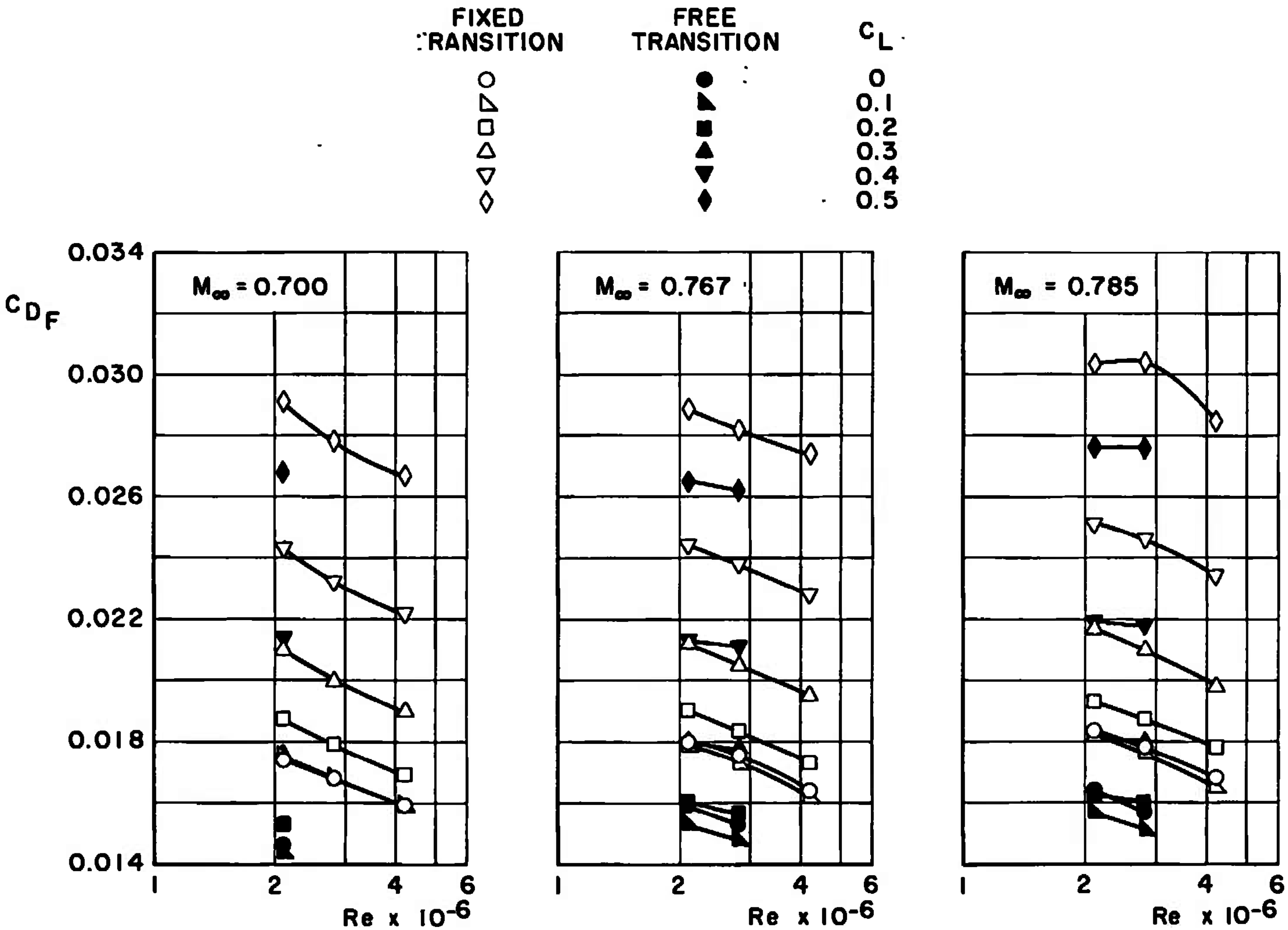


Fig. 12 Variation of C_{D_F} with Reynolds Number for Fixed and Free Transition for the Configuration with Empennage, Pylons, and Nacelles Off

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Reynolds number effects						
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axial-force characteristics						
transonic flow						
wind tunnel tests						
aerodynamic characteristics						

1. Airplanes -- Stability
2 " -- Reynolds number effects
3 " -- axial forces
4 " -- C-5A
5 " -- Lift
6 " -- Pitching moment

7 - 2