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VARIATION OF PITCHING MOMENT WITH ENGINE THRUST FOR A TWIN-ENGINE COMMERCIAL JET AIRCRAFT

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16. Abstract

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SUMMARY

Flight tests were made to determine the effect of engine net thrust on airplane pitching moment for a twin-engine commercial jet transport in the approach, climbout and descent, and cruise configurations. The results indicate that for all the conditions analyzed, the pitching moment due to thrust is somewhat higher than that estimated from the product of net thrust and its moment arm (perpendicular distance from thrust axis to the airplane center of gravity). The differences are attributed to additional moments produced by nacelle normal force, jet-induced downwash, and interaction between wing flow and engine nacelle flow.

INTRODUCTION

Flight tests have been made to determine various aerodynamic parameters for a technical data base for a twin-engine commercial jet transport. This data base will be used to implement studies for terminal area research. The standard handling qualities have been obtained from flight tests of the aircraft and are presented in reference 1. One specific area for which no flight data had been obtained is the variation of pitching moment with net thrust change. The value of this parameter, used in the fixed-base simulator at Langley Research Center (LRC), is the product of the thrust increment and the moment arm of the engine-thrust axis to the airplane center of gravity (the simulator represents the test airplane). Flight tests have been conducted, therefore, to provide data to verify moment due to thrust.

SYMBOLS

Values are given in both SI and U.S. Customary Units. Measurements were made in U.S. Customary Units.

C_m pitching-moment coefficient, $M_Y/qS\bar{c}$

C_{m_α} $= \partial C_m/\partial \alpha$

$C_{m_{\delta_e}}$ elevator effectiveness parameter, $\partial C_m/\partial \delta_e$

$\bar{c}$ wing mean geometric chord, m (ft)

I_{XX}, I_{YY}, I_{ZZ} moments of inertia about X-, Y-, and Z-axes, kg-m^2 (slug-ft^2)

M_Y pitching moment, N-m (ft-lbf)

q dynamic pressure, $\frac{1}{2}\rho V^2$, N/m^2 (lbf/ft^2)

S wing area, m^2 (ft^2)

V true airspeed, m/sec (ft/sec)

α angle of attack, deg

δ_e elevator deflection (trailing edge down, positive), deg

ρ air density, kg-m^3 (slug-ft^3)

Abbreviations:

EPR engine pressure ratio (ratio of total pressure at turbine exit to total pressure at engine inlet)

KIAS indicated airspeed, knots (1 knot = 0.51 m/sec)

LRC Langley Research Center

DESCRIPTION OF AIRPLANE

A photograph of the test airplane is shown in figure 1. The airplane is equipped with triple-slotted trailing-edge flaps, leading-edge slots, and Krueger leading-edge flaps inboard; this vehicle was designed for short haul operations into existing small airports with short runways. Pitch control is achieved by an elevator and a movable stabilizer; lateral control is obtained by a combination of ailerons and spoilers. A single surface rudder provided directional control. A more complete description of the airplane and the experimental systems is given in reference 1. A three-view drawing of the airplane is shown in figure 2; mass and additional geometric details are presented in table I.

TEST CONDITIONS AND PROCEDURES

The conditions and procedures for this series of tests are presented in table II. The three aircraft configurations considered covered the range of aircraft operations: approach, climbout and descent, and cruise. All the tests were flown with the basic aircraft control systems. During the tests the outboard fuel tanks were full, and fuel was used only from the center fuel tank. This fuel management was used to minimize change in center-of-gravity location because the position of the fuel in the center tank varied less as a result of airplane pitch attitude than the position of the fuel in the outboard tanks. During the tests, the weight of the airplane varied from 411 460 N (92 500 lbf) to 384 770 N (86 500 lbf). The tests were made at altitudes from 1219 m (4000 ft) to 4267 m (14 000 ft).

DATA ACQUISITION AND REDUCTION

Data were recorded on board the aircraft on a wide-band magnetic tape recorder at 40 samples per sec using the piloted aircraft data system (PADS) at LRC. Typical data consisted of triaxial body angular position and rate information as well as pilot control inputs plotted against time.

Edited flight data were obtained through "quick-look" strip charts provided by the research aircraft ground station (RAGS) at LRC. Computer-compatible digital tapes of desired data were again generated using the RAGS. These tapes were processed by the LRC Analysis and Computation Division computers, and output tapes of engineering units resulted. Final report data were obtained from computer plots generated from the engineering units tapes.

Figure 3 is a portion of a computer plot which provided the data from which thrust and pitching moment were computed. After the thrust for each test condition was determined from the engine pressure ratio (EPR) value with reference to unpublished engine data, it was corrected for the air density at the test altitude and Mach number.

It should be noted that the moment obtained is the pitching moment produced by reduction in the thrust and, hence, has the opposite sign to the thrust pitching moment. Each pitching moment was calculated using (a) the elevator angle and angle of attack obtained from the time history, (b) the dynamic pressure for the test condition, and (c) the elevator effectiveness and pitching moment due to angle of attack from reference 2. Thus, Moment = $\left(C_{m_{\delta_e}} \delta_e + C_{m_\alpha} \Delta\alpha\right) qS\bar{c}$. The values of the elevator effectiveness parameter $C_{m_{\delta_e}}$ used are -0.0390/deg for the approach condition and -0.0285/deg for the cruise and climbout and descent conditions. The value of C_{m_α} used is -0.030/deg. These values apply to conditions at sea level and Mach number 0; they were corrected for flexibility and Mach number.

RESULTS AND DISCUSSION

The results of the flight tests to determine the variation of elevator pitching moment with engine thrust are presented in figure 4. Straight-line least-squares-fairing curves were fitted to the test points because the scatter in the points appears to be random. The slopes and intercepts of these straight lines are summarized in table III. Plotted for comparison is the estimated variation of pitching moment with thrust change which was computed to be the product of thrust change and the geometric moment arm from the thrust axis to the airplane center of gravity. For the landing approach configuration (landing gear down), this moment arm measures 1.22 m (4.0 ft); for the climbout and descent and cruise configurations (landing gear up), it is 1.28 m (4.2 ft). The simulator uses an early value of 1.52 m (5.0 ft) for all configurations and has not been updated to the values just given.

In seven of the eight test runs there is a positive elevator moment at the initial test point or maximum thrust for each run. The positive moment occurs because the stabilizer was not trimmed to reduce the elevator quite to 0°. The greatest initial elevator deflection, however, was only -1.6°.

The test data presented in figure 4 and in table III show that in all cases the variation in pitching moment with thrust was greater than that estimated as the product of thrust change and the actual moment arm (1.22 or 1.28 m (4.0 or 4.2 ft) depending on the configuration). In the approach configuration measured moments are only about 12 percent greater than the estimated values, but for the climbout and descent and the cruise configurations the measured moments are 25 and 28 percent higher, respectively. These results agree qualitatively with the results of reference 3 which showed that in addition to the direct thrust moment, there are moments due to jet-induced downwash acting on the horizontal tail and moments due to the normal force produced on the nacelle inlets as the air turns through the angle of attack of the thrust axis. There may also be moments due to interaction between wing flow and engine nacelle flow.

The results are summarized in figure 5 which presents the variation of moment arm with configuration. The data of figure 5 show that both the effective moment arm (that is, the slopes shown in fig. 4 and table III) and geometric moment arm decrease with increase in flap angle, the effective moment arm being larger than the geometric arm. Comparison of the curves shows that the difference between the effective and geometric moment arms decreases with increasing flap angle. This decrease indicates that for the test airplane the secondary effects of thrust on pitching moment decrease with increasing flap angle.

CONCLUDING REMARKS

Flight tests were made to determine the effect of engine net thrust on airplane pitching moment for a twin-engine commercial jet transport in the approach, climbout and descent, and cruise configurations. The results indicate that for all the conditions analyzed, the pitching moment due to thrust is somewhat higher than that estimated from the product of net thrust and its moment arm (perpendicular distance from thrust axis to the airplane center of gravity). The differences are attributed to additional moments produced by nacelle normal force, jet-induced downwash, and interaction between wing flow and engine nacelle flow.

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August 3, 1977

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2. Paulson, John W., Jr.: Wind-Tunnel Results of the Aerodynamic Characteristics of a 1/8-Scale Model of a Twin-Engine Short-Haul Transport. NASA TM X-74011, 1977.

3. Ribner, Herbert S.: Field of Flow About a Jet and Effect of Jets on Stability of Jet-Propelled Airplanes. NACA WR L-213, 1946. (Formerly NACA ACR L6C13.)

TABLE I.- AIRPLANE DIMENSION AND DESIGN DATA

General:	
Length, m (ft)	28.65 (94)
Height to top of vertical fin, m (ft)	11.28 (37)
Wing:	
Area, m^2 (ft^2)	91.04 (980)
Span, m (ft)	28.35 (93.0)
Mean aerodynamic chord, m (ft)	3.41 (11.2)
Incidence angle, deg	1.0
Aspect ratio	8.83
Dihedral, deg	6
Sweep, deg	25
Flap deflection (maximum), deg	40
Flap area, m^2 (ft^2)	14.94 (160.8)
Aileron deflection (maximum), deg	±20
Spoiler deflection, deg:	
Inboard	60
Outboard	40
Stabilizer:	
Area, m^2 (ft^2)	28.98 (312)
Span, m (ft)	10.97 (36)
Stabilizer deflection, deg	12
Elevator deflection (maximum), deg	±21
Vertical tail:	
Total area, m^2 (ft^2)	20.9 (225)
Span, m (ft)	6.15 (20.16)
Rudder area, m^2 (ft^2)	5.22 (56.2)
Rudder deflection, deg	±24
Weight:	
Maximum takeoff gross weight, N (lb)	4.35×10^5 (97 800)
Maximum landing weight, N (lb)	3.98×10^5 (89 700)
Empty weight (zero fuel), N (lb)	2.82×10^5 (63 500)
Moments of inertia for 4.00×10^5 N (90 000 lb) condition:	
I_{XX}, kg-m^2 (slug-ft^2)	610 100 (450 000)
I_{YY}, kg-m^2 (slug-ft^2)	1 098 200 (810 000)
I_{ZZ}, kg-m^2 (slug-ft^2)	1 789 700 (1 320 000)
Center of gravity:	
Mean aerodynamic chord, percent	15

TABLE II.- TEST CONDITIONS AND PROCEDURES

Aircraft conditions		Procedures
Configuration	Indicated airspeed, knots	
Approach; gear down; flaps 40°	115 134 164	At each condition stabilizer was trimmed for takeoff power (EPR approximately 2.00). Power was decreased in steps of approximately 0.15 EPR to idle (EPR approximately 1.05) while constant airspeed was maintained with elevator; thus, flight-path angle was allowed to vary as needed.
Climbout and descent; gear up; flaps 15°	130 150 188	
Cruise; gear up; flaps 0°	252 300	

TABLE III.- TABULATED FAIRINGS OF PITCHING MOMENT

PLOTTED AGAINST THRUST

Configuration	Indicated airspeed, knots	Slope		Intercept	
		N-m/N	ft-lbf/lbf	N-m	ft-lbf
Approach (gear down):	115	-1.41	-4.63	143 700	105 993
	134	-1.33	-4.36	128 300	94 634
	164	-1.38	-4.53	94 900	69 998
Slope average		-1.37	-4.49		
Thrust × 1.22 m (4.0 ft)		-1.22	-4.00	122 000	89 987
Climbout and descent (gear up):	130	-1.75	-5.74	171 900	126 793
	150	-1.59	-5.22	187 300	138 152
	188	-1.46	-4.79	164 100	121 040
Slope average		-1.60	-5.25		
Thrust × 1.28 m (4.2 ft)		-1.28	-4.20	128 000	94 413
Cruise (gear up):	252	-1.43	-4.69	208 400	153 716
	300	-1.86	-6.10	260 100	191 850
Slope average		-1.64	-5.38		
Thrust × 1.28 m (4.2 ft)		-1.28	-4.20	128 000	94 413

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Figure 1.- Test airplane.

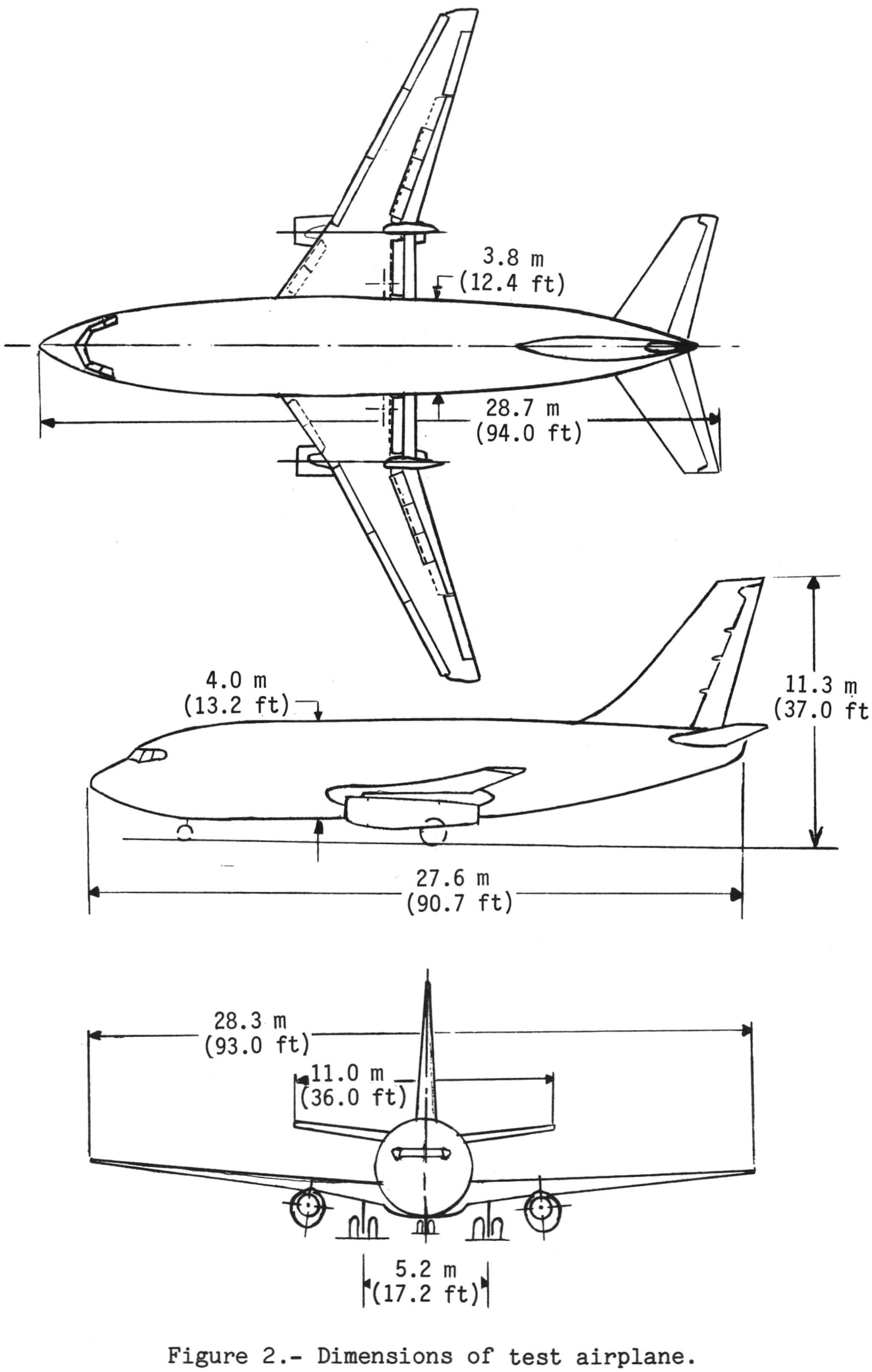

Figure 2.- Dimensions of test airplane.

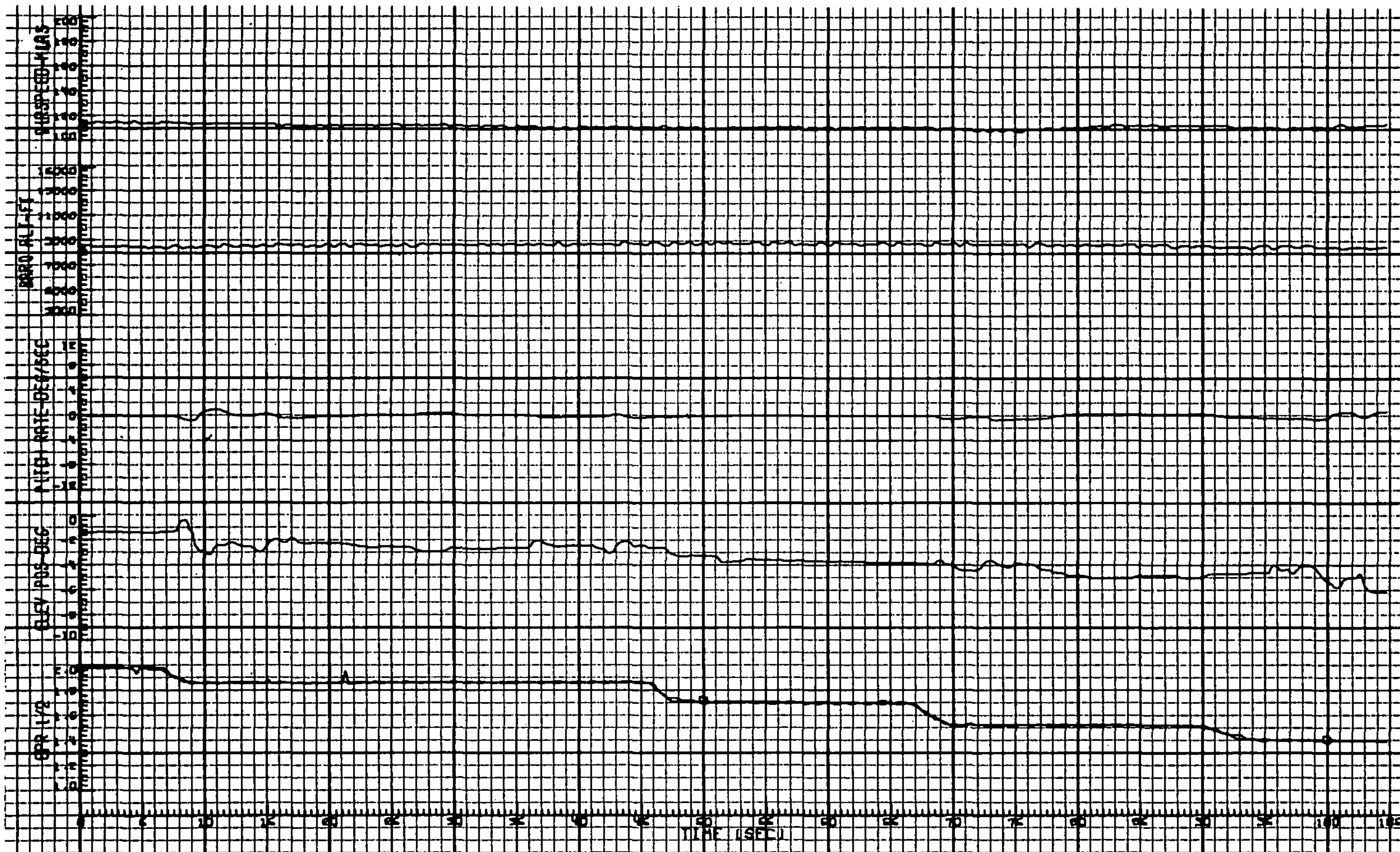

Figure 3.- Representative section of time history of flight data. (1 ft = 0.3048 m.)

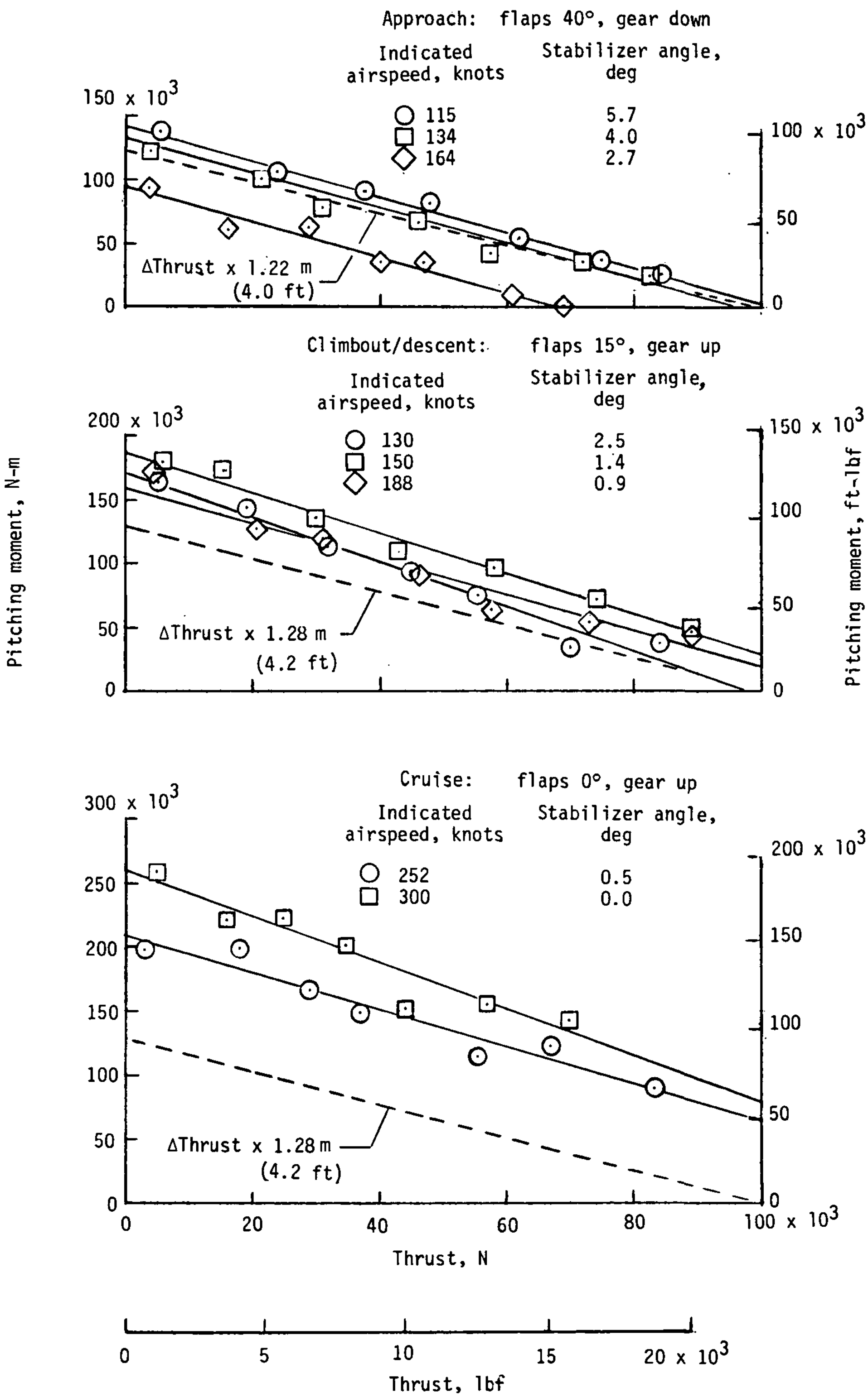

Figure 4.- Variation of pitching moment with thrust.

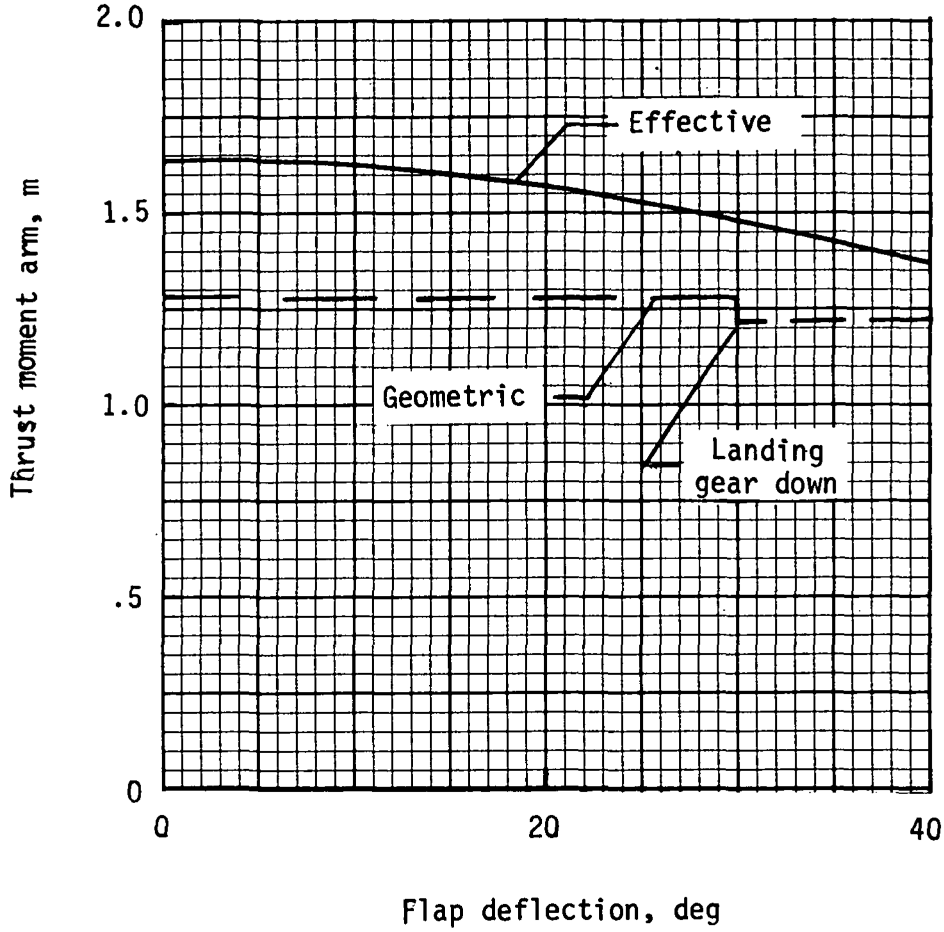

Figure 5.- Variation of thrust moment arm with flap deflection.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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