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SUMMARY

A study was conducted to determine the effects of laminar flow control on the performance of a large span-distributed-load flying-wing cargo airplane concept having a design payload of 2.669 MN (600 000 lbf) and range of 5.93 Mm (3 200 n.mi.). Two configurations were considered. One employed laminarized flow over the entire surfaces of the wing and vertical tails, with the exception of the estimated areas of interference due to the fuselage and engines. The other case differed only in that laminar flow was not applied to the flaps, elevons, spoilers, or rudders. The two cases are referred to as the 100 percent and 80 percent laminar configurations, respectively.

The utilization of laminar flow control results in reductions in the standard day, sea level installed maximum static thrust per engine from 240 kN (54 000 lbf) for the non-LFC configuration to 205 kN (46 000 lbf) for the 100 percent laminar configuration and 209 kN (47 000 lbf) for the 80 percent case. Weight increases due to the LFC systems cause increases in the operating empty weights of approximately 3 to 4 percent. The design takeoff gross weights decrease approximately 3 to 5 percent. The FAR-25 takeoff field distances for the LFC configurations are greater by about 6 to 7 percent. Block times are virtually unaffected by the utilization of LFC. As compared to the non-LFC configuration, block fuel weights are reduced 24 percent for the 100 laminar configuration and 18 percent for the 80 percent case. Fuel efficiencies for the respective configurations are increased 33 percent and 23 percent.

INTRODUCTION

The endeavor of providing the most efficient airplane practicable has become especially important in recent years because of the increasingly high cost of aircraft fuels. One method of improving aerodynamic efficiency is that of reducing drag through laminar flow control. In this method, suction is employed to remove a portion of the boundary layer through small perforations or slots in the aircraft skin. The effect is to shift the point of transition downstream, thus increasing the area affected by laminar flow.

Based on the assumption that a practical laminar flow control system may be available in the 1990's, a study was conducted wherein the effects of a laminar flow control system on aircraft performance were evaluated for the airplane concept of reference 1. This aircraft is envisioned as a type of large cargo airplane possibly becoming operational in about the same time period. A configuration study (ref. 2) was performed by the Vought Corporation, Hampton Technical Center, under the auspice of the Vehicle Integration Branch, Aeronautical Systems Division, Langley Research Center.

The purpose of the present paper is to summarize the contracted analysis and, by comparison with the study of reference 1, to indicate the gains which could be expected from the application of laminar flow control to an advanced flying-wing cargo transport.

SYMBOLS AND NOTATION

Values are presented in both SI and U.S. Customary Units. The measurements were made in U.S. Customary Units.

c	local chord
$\bar{c}$	mean aerodynamic chord
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
$C_{D,p_{min}}$	minimum parasite drag coefficient
C_f	total average skin friction coefficient
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_p	pressure coefficient
C_{SP}	suction power coefficient, $\frac{\text{Suction power}}{\frac{1}{2}\rho_\infty V_\infty^3 S}$
DOC	direct operating cost
f	equivalent flap plate area
KEAS	equivalent airspeed, knots
LFC	laminar flow control
M	Mach number
OWE	operating weight, empty
q	dynamic pressure
R	Reynolds number

S	reference wing area
S_v	area per vertical tail
s	surface distance along airfoil, measured from leading edge
T	sea level, standard day installed static thrust per engine
TOGW	takeoff gross weight
TSFC	thrust specific fuel consumption
V	velocity
W_f	fuel weight
ρ	density

Subscripts:

l	local
lam	laminar flow
s	suction slot
turb	turbulent flow
∞	freestream

DISCUSSION

Configurations

The study was conducted to determine the effects of the application of laminar flow control (LFC) on the performance of the large flying-wing cargo airplane concept of reference 1. (See figure 1 for configuration details). The mission requirement of the reference aircraft was that of transporting 2.669 MN (600 000 lbf) of containerized cargo (maximum container cross section of 2.44m x 2.44m (8 ft x 8 ft) over a distance of approximately 5.93 Mm (3200 n.mi.). The primary design philosophy in configuring the aircraft was to distribute the payload along the wing span in order to counterbalance the aerodynamic loads as much as possible, thus minimizing the in-flight wing bending moments and shear forces.

In the LFC study the exterior dimensions, excluding nacelle size, remained unchanged since these dimensions are determined almost soley by the cargo dimensions. Engine type and design payload and range were held constant. Engine size, operating empty weight, and mission fuel weight were adjusted to those required for the LFC configurations. Although the locations of the suction pumps were not considered in the study, ample unused wing volume rearward of the wing rear spar is available for the pumping systems. Several independent systems would be used to minimize the length of ducting between the slots and the pumps.

Two LFC configurations were evaluated. The first employed an LFC system over the entire surfaces of the wing and vertical tails, with the exception of the estimated areas of interference due to the fuselage and engines. These interference areas were 37.2 m^2 (400 ft^2) and 24.5 m^2 (264 ft^2) for the fuselage and engines, respectively; or only approximately 1.5 percent of the total wetted area of the wing and vertical tails. The second configuration differed only in that the LFC system was not applied to the flaps, elevons, spoilers, or rudders. These two configurations are referred to as the 100 percent and 80 percent laminar cases, respectively.

LFC System Weights

The wing was assumed to be of aluminum honeycomb construction. The LFC system weights for the two configurations are presented in table I. The values of weight increment per unit surface area were obtained from progress reports submitted during the course of a NASA-contracted laminar-flow-control study currently being conducted by the Boeing Commercial Airplane Company. It should be noted that these weight increments include the weight of the associated pumping and ducting system, as well as the incremental weight of the surface structure.

Drag Polars

The drag polars for the 100 percent and 80 percent laminar configurations are shown in figures 2(a) and 2(b) along with the polars representing the non-LFC case (ref. 1). It was estimated that there would be a one-third reduction in interference drag at the juncture of the wing and vertical tails because of flow laminarization. Typical calculations of the minimum parasite drag coefficients, at a cruise Mach number of 0.75, are presented in table II.

A maximum Reynolds number of 6.56×10^6 per m (2.00×10^6 per ft) was specified for the effective operation of the LFC system. This Reynolds number limitation required a reduction in the climb velocity from 280 KEAS for the non-LFC configuration (ref. 1) to 250 KEAS. Performance claculations (subsequently to be discussed) indicate that the LFC system should be activated when the aircraft reaches a Mach number of 0.72 and an altitude of 9.69 km (31 800 ft). The cruise Mach number of 0.75 is the same as that for the configuration of reference 1. Hence, the LFC drag polars are applicable only during the latter part of the climb ($M \geq 0.75$) and throughout the cruise segment.

LFC Power Requirement and Equivalent Drag

At a given location on the surface of an LFC configuration the coefficient of suction power required to operate the system (excluding losses due to ducts, valves, and pumps) may be approximated by the equation

$$C_{SP,l} = \frac{\rho_l V_s}{\rho_\infty V_\infty} - C_{p,l} \frac{V_s}{V_\infty} \tag{1}$$

Equation 1 is essentially the same as that derived in reference 3, except that the local and freestream densities are not assumed to be equal. The airfoil pressure coefficients, calculated by the method of reference 4, are shown in figure 3 for the design Mach number and lift coefficient. The suction flow velocity, V_s, and density, ρ_l, were determined with the use of the computer program described in reference 5. This program calculates the compressible boundary layer and suction flow characteristics over a yawed infinite wing. Constant velocity suction flow along segments of the chord normal to the leading edge were input into the program in a trial-and-error manner until complete laminarization was achieved. For the present study, the final distribution of the ratio of local suction flow density to that of the freestream density is shown in figure 4. The variation of the ratio of suction flow velocity to that of the freestream velocity is presented in figure 5. The resultant distribution of the suction power coefficient along the chord, as determined by equation 1, is shown in figure 6. These data were integrated to determine the suction power coefficients of the laminarized spanwise stations of the airfoils. The integrations were performed to the trailing edge for the 100 percent laminar case, and to the control-surface hinge lines for the 80 percent case. Since the wing is untapered, the suction power coefficient is invariant along the span, and thus, the suction power coefficient of the wing is equal to that of the airfoil except for a reduction to account for the nonlaminarized areas. This reduction was estimated to be 10 percent. Thus

$$C_{SP,wing} = 0.9\ C_{SP,airfoil} \tag{2}$$

The values of suction power coefficient for the wing are 0.0015 and 0.0014 for the 100 percent and 80 percent laminar cases, respectively. The suction power coefficient for the tails could not be calculated by the same method since the airloads were not as well defined as those for the wing. It was therefore assumed that the magnitude of the suction power coefficient (based on the referenced wing area) for the tails relative to the wing is proportional to the areas of the respective components. Therefore, the total suction power coefficient for the airplane is

$$C_{SP,total} = 0.9\ C_{SP,airfoil}\left(1 + \frac{2S_V}{S}\right) \tag{3}$$

The total suction power coefficients are 0.0017 and 0.0016 for the 100 percent and 80 percent laminar cases, respectively.

The suction power may be expressed as

$$\text{suction power} = C_{SP}\left(\frac{1}{2}\rho_\infty V_\infty^3 S\right) \tag{4}$$

$$= \left(C_{SP}\ \frac{1}{2}\rho_\infty V_\infty^2 S\right) V_\infty \tag{5}$$

Since power equals the product of force times velocity, the term within the brackets of equation 5 may be considered an equivalent drag, with C_{SP} an equivalent drag coefficient. Thus, for each LFC configuration, the equivalent increase in drag coefficient due to the total suction power requirement is equal to the total suction power coefficient determined by equation 3.

Weight Adjustments, Engine Resizing, and Performance

As previously mentioned, the aircraft exterior dimensions, excluding those of the nacelles, remained unchanged, as did engine type, and design payload (2.669 MN (600 000 lbf)) and range (5 926 km (3200 n.mi.)). However, engine size, operating empty weight, and mission fuel weight were adjusted to the requirements for each of the LFC configurations. Mission performance was evaluated with the use of the Vehicle Integration Branch long-range-cruise mission analysis program developed at the Langley Research Center. The fuel requirements for taxi, takeoff, and descent were adjusted to reflect changes in aircraft weight and engine size.

The required operating empty weight, mission fuel weight, and engine size for each LFC configuration were determined in two basic steps. In the first step the design range and engine size were assumed to be equal to those of reference 1. Using the mission analysis program, fuel weight and operating empty weight (as a function of fuel weight) were determined. For the 100-percent-LFC configuration, the operating empty weight was 1.872 MN (420 800 lbf) and the mission fuel weight was 1.359 MN (305 500 lbf). For the 80 percent LFC case the operating empty weight was 1.846 MN (414 900 lbf) and the fuel weight was 1.438 MN (323 300 lbf).

In the second step these mission fuel weights were held constant and the operating empty weights were varied as a function of engine size (or thrust). These weights were then input into the mission analysis program to determine range and performance. The estimated effects of engine thrust on operating empty weight, the resultant design takeoff gross weight, and the calculated range for the 100 percent and 80 percent laminar configurations are shown in figures 7(a) and 7(b), respectively. For engine thrusts less than those shown in these figures, the service ceilings at the beginning of cruise were too low to meet the aforementioned maximum Reynolds number requirement for effective LFC operation. The total decrease in the weights of the six engines are 259 kN (58 300 lbf) for the 100 percent LFC case and 223 kN (50 200 lbf) for the 80 percent configuration. The mission performance of the 100 percent and

80 percent laminar configurations with the minimum-scale engines are presented in tables III(a) and III(b), respectively.

Effects of LFC

The more significant parameters for the two configurations studied are compared with the non-LFC configuration (ref. 1) in table IV. The reductions of both drag and gross weight at the beginning of cruise (due to the application of LFC) results in decreases in the sea level, standard day installed maximum static thrust per engine from 240 kN (54 000 lbf) for the non-LFC configuration to 205 kN (46 000 lbf) for the 100 percent laminar configuration and 209 kN (47 000 lbf) for the 80 percent case.

Although there are small decreases in the weights of some of the wing primary structural components of the LFC configurations due to lower fuel weights, the additional weights due to the LFC systems result in small overall increases in the operating empty weights of 4.1 percent and 3.3 percent for the 100 percent and 80 percent laminar configurations, respectively.

Because of the significant reductions in cruise drag afforded by the LFC systems, mission fuel weights (block fuel plus reserves minus taxi-in) are reduced 21.8 percent for the 100 percent LFC configuration and 16.2 percent for the 80 percent laminar case. The resulting design takeoff gross weights (operating empty weight plus mission fuel weight plus the 2.669 MN (600 000 lbf) payload) decrease 4.8 percent and 3.5 percent for the 100 percent and 3.5 percent for the 100 percent and 80 percent LFC configurations, respectively.

The FAR-25 takeoff field distance, which is 2.5 km (8200 ft) for the non-LFC configuration, is increased by approximately 159 m (520 ft) for the 100 percent laminar configuration and by about 177 m (580 ft) for the 80 percent case. Although takeoff field distance would be shortened for the laminar configurations due to the lower wing loadings, this advantage is slightly outweighed by the lower thrust-to-weight ratios.

Block time (engine start to engine shutdown) is virtually unchanged from that of the reference 1 configuration. As compared to the non-LFC configuration, block fuel weights are reduced 24 percent for the 100 percent laminar configuration and 18 percent for the 80 percent case. The fuel efficiencies for the respective configurations are increased 33 percent and 23 percent.

Lack of operational experience with laminar-flow-control aircraft precludes an accurate estimate of airframe price or maintenance cost. Therefore, direct operating costs were estimated assuming that all DOC parameters except fuel are equal to those of the reference 1 configuration. For a fleet size of 100 aircraft and a fuel price of $0.42 per gallon, the reduction in DOC due to the application of LFC is 10 percent for the 100 percent LFC configuration and 7 percent for the 80 percent case. For the same fleet size and a fuel price of $1.20 per gallon, DOC is reduced 20 percent for the 100 percent LFC configuration and 17 percent for the 80 percent case.

CONCLUSIONS

A study was conducted to determine the effects of laminar flow control on the performance of a large span-distributed-load flying wing cargo airplane concept having a design payload of 2.669 MN (600 000 lfb) and range of 5.93 Mm (3 200 n.mi.). Two configurations were considered. One employed laminarized flow over the entire surfaces of the wing and vertical tails, with the exception of the estimated areas of interference due to the fuselage and engines. The other case differed only in that laminar flow was not applied to the flaps, elevons, spoilers, or rudders. The two cases are referred to as the 100 percent and 80 percent laminar configurations, respectively. The conclusions are as follows:

1. The utilization of laminar flow control results in reductions in the standard day, sea level installed maximum static thrust per engine from 240 kN (54 000 lbf) for the non-LFC configuration to 205 kN (46 000 lbf) for the 100 percent laminar configuration and 209 kN (47 000 lbf) for the 80 percent case.

2. Weight increases due to the LFC systems cause increases in the operating empty weights of approximately 3 to 4 percent. The design takeoff gross weights decrease approximately 3 to 5 percent.

3. The FAR-25 takeoff field distances for the LFC configurations are greater by about 6 to 7 percent.

4. Block times are virtually unaffected by the utilization of LFC.

5. As compared to the non-LFC configuration, block fuel weights are reduced 24 percent for the 100 laminar configuration and 18 percent for the 80 percent case. Fuel efficiencies for the respective configurations are increased 33 percent and 23 percent.

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TABLE I. - LFC SYSTEM WEIGHTS

	100 percent laminarized configuration			80 percent laminarized configuration		
	Projected Laminarized area, m^2 (ft^2)	Weight increment per unit area, N/m^2 (lbf/ft^2)	Weight increment N (lbf)	Projected Laminarized area, m^2 (ft^2)	Weight increment per unit area,	Weight increment N (lbf)
Wing (structure, ducts, and valves)	1,662.6 (17,896)	60.329 (1.26)	100,303 (22,549)	1,310.7 (14,108)	60.329 (1.26)	79,073 (17,776)
Suction engine for wing	1,662.6 (17,896)	33.516 (0.7)	55,724 (12,527)	1.310.7 (14,108)	33.516 (0.7)	43,929 (9,876)
Suction engine for vertical tail (assumed to be part of wing weight	219.4 (2,362)	33.516 (0.7)	7,353 (1,653)	188.8 (2,032)	33.516 (0.7)	6,328 (1,423)
Total increase in wing weight due to LFC			163,380 (36,729)			129,330 (29,075)
Vertical tails	219.4 (2,362)	60.329 (1.26)	13,236 (2,976)	188.8 (2,032)	60.329 (1.26)	11,390 (2,560)
Total OWE increase due to LFC			176,616 (39,705)			140,720 (31,635)

TABLE II. - CALCULATION OF MINIMUM PARASITE DRAG COEFFICIENT, M = 0.75

Airplane component	R x10^{-6}	Drag Item	Turbulent C_f	Turbulent f, m^2	Turbulent f, ft^2	100% laminar C_f	100% laminar f, m^2	100% laminar f, ft^2	80% laminar C_f	80% laminar f, m^2	80% laminar f, ft^2
Wing	118.0	Uncorrected flat plate	0.001921	6.994	75.28	0.000110	0.400	4.31	0.000546	2.012	21.66
		Supervelocity		2.239	24.10		.128	1.38		.644	6.93
		Pressure		.670	7.21		.038	.41		.193	2.08
		Roughness		.211	2.27		.012	.13		.012	.13
		Excrescencies		.622	6.70		.311	3.35		.311	3.35
		Wing-body interference		.186	2.00		.186	2.00		.186	2.00
		Total, wing		10.922	117.56		1.075	11.58		3.358	36.15
Tails	44.6	Uncorrected flat plate	.002210	0.980	10.55	.000180	0.080	.86	.000505	0.224	2.41
		Supervelocity		.151	1.62		.012	.13		.034	.37
		Pressure		.005	.05		.001	.01		.001	.01
		Roughness		.031	.33		.003	.03		.003	.03
		Excrescencies		.085	.91		.042	.45		.042	.45
		Wing-tail interference		.931	10.02		.621	6.68		.621	6.68
		Total, tails		2.183	23.48		.759	8.16		.925	9.95
Total, wing and tails				13.105	141.04		1.834	19.74		4.283	46.10
Total airplane $C_{D,p_{min}}$						* 0.00405			* 0.00547		

Total turbulent $C_{D,p_{min}}$ = 0.01059

$$* \text{ Total laminar } C_{D,p_{min}} = 0.01059 - \frac{\left(f_{turb} - f_{lam}\right)_{wing + tails}}{S}$$

TABLE III. - MISSION PERFORMANCE

(a) 100 percent LFC Configuration

(Taxi-in fuel taken out of reserves at destination. Civil Aeronautics Board range equals trip range minus allowances for maneuver, traffic, and airway distance)

(a) Aircraft characteristics

Takeoff gross weight, N (lbf)	5 760 447	(1 295 000)
Operating weight, empty, N (lbf)	1 790 409	(405 500)
Payload, gross, N (lbf)	2 668 933	(600 000)
Wing area, m^2 (ft^2)	1 724	(18 560)
Installed sea-level static thrust, per engine, standard day, N(lbf)	204 618	(46 000)
Takeoff thrust-weight ratio		0.213
Takeoff wing loading, N/m^2 (lbf/ft^2)	3337	(69.7)

(b) Design mission

Flight Mode	Gross weight, N (lbf)	ΔFuel, N (lbf)	ΔRange, km (n.mi.)	ΔTime min
Takeoff	5 760 447 (1 295 000)			
		21 351 (4 800)	0	11
Start climb	5 739 096 (1 290 200)			
		152 574 (34 300)	393 (212)	36
Start cruise	5 586 522 (1 255 900)			
		826 480 185 800	5154 (2783)	386
End cruise	4 760 042 (1 070 100)			
		19 127 (4 300)	370 (200)	20
End descent	4 740 915 (1 065 800)			
Taxi-in	4 734 087 (1 064 265)	6 828 (1535)	0	5
Block fuel and time		1 026 360 (230 735)		458
Trip range			5917 (3195)	

(c) Reserve fuel breakdown

10-percent trip time, N (lbf)	87 630 (19 700)
Missed approach, N (lbf)	15 124 (3 400)
370 km (200 n.mi.) to alternate airport, N (lbf)	113 874 (25 600)
30 minutes holding at 457 m (1500 ft), N (lbf)	64 944 (14 600)
Total reserve fuel	281 572 (63 300)

(d) Initial cruise conditions

C_L	0.3207
C_D	0.01253
L/D	25.60
TSFC, kg/N-hr (lbm/lbf-hr)	(0.636)
Altitude, m (ft)	10 211 (33 500)

(e) Fuel efficiency

Payload of fuel burned, Mg-km/N (ton-n.ni./lbf)	1.57 (4.15)

TABLE III. - MISSION PERFORMANCE

(b) 80 percent LFC configuration

(Taxi-in fuel taken out of reserves at destination. Civil Aeronautics Board range equals trip range minus allowances for maneuver, traffic and airway distance)

(a) Aircraft characteristics

Takeoff gross weight, N (lbf)	5 839 625	(1 312 800)
Operating weight, empty, N (lbf)	1 777 065	(399 500)
Payload, gross, N (lbf)	2 668 933	(600 000)
Wing area, m^2 (ft^2)	1 724	(18 560)
Installed sea-level static thrust, per engine, standard day, M, lbf	209 066	(47 000)
Takeoff thrust-weight ratio		0.215
Takeoff wing loading, N/m^2 (lbf/ft^2)	3385	(70.7)

(b) Design mission

Flight Mode	Gross weight, N (lbf)	ΔFuel, N (lbf)		ΔRange, km (n.mi.)	ΔTime, min
Takeoff	5 839 625 (1 312 800)				
		21 633	(4 870)	0	11
Start climb	5 817 963 (1 307 930)				
		160 580	(36 100)	419 (226)	37
Start cruise ...	5 657 382 (1 271 830)				
		902 099	(202 800)	5137 (2774)	386
End cruise	4 755 282 (1 069 030)				
		19 572	(4 400)	370 (200)	20
End descent	4 735 710 (1 064 630)				
Taxi-in	4 728 726 (1 063 060)	6 984	(1 570)	0	5
Blcok fuel and time		1 110 899	(249 740)		459
Trip range				5926 (3200)	

(c) Reserve fuel breakdown

10-percent trip time, N (lbf)	95 059	(21 370)
Missed approach, N (lbf)	15 435	(3 470)
370 km (200 n.mi.) to alternate airport ..	114 230	(25 680)
30 minutes holding at 457 m (1500 ft) N (lbf)	65 166	(14 650)
Total reserve fuel	289 891	(65 170

(d) Initial cruise conditions

C_L	0.3404
C_D	0.01462
L/D	23.28
TSFC, kg/N-hr (lbm/lbf-hr)	(0.628)
Altitude, m (ft)	10 516 (34 500)

(e) Fuel efficiency

Payload of fuel burned, Mg-km/N (ton-n. mi./lbf)............................	1.45 (3.84)

TABLE IV. - EFFECTS OF LFC

Design range = 5926 km(3200 n.mi.)

Design payload = 2 668 933 N (600 000 lbf)

	Non-LFC Configuration	100% laminar configuration	% change from non-LFC conf.	80% laminar configuration	% change from non-LFC configuration
Thrust per engine, N (lbf)	240 200 (54 000)	204 600 (46 000)	-14.8	209 100 (47 000)	-13.0
Operating empty weight, N (lbf)	1 719 682 (386 600)	1 790 409 (402 500)	4.1	1 777 065 (399 500)	3.3
Mission fuel, N (lbf) (Block + reserves - taxi-in)	1 663 635 (374 000)	1 301 105 (292 500)	-21.8	1 393 628 (313 300)	-16.2
Design TOGW, N (lbf)	6 052 250 (1 360 600)	5 760 447 (1 295 000)	-4.8	5 839 628 (1 312 800)	-3.5
Takeoff field length, m (ft)	2499 (8200)	2658 (8720)	6.3	2676 (8780)	7.1
Block time, min	454	458	1.0	459	1.1
Block fuel, N (lbf)	1 355 800 (304 800)	1 026 200 (230 700)	-24.3	1 110 700 (249 700)	-18.1
Fuel efficiency, Tonne-km per N of fuel (ton-n.mi. per lbf of fuel)	1.19 (3.15)	1.57 (4.16)	32.1	1.45 (3.84)	21.9

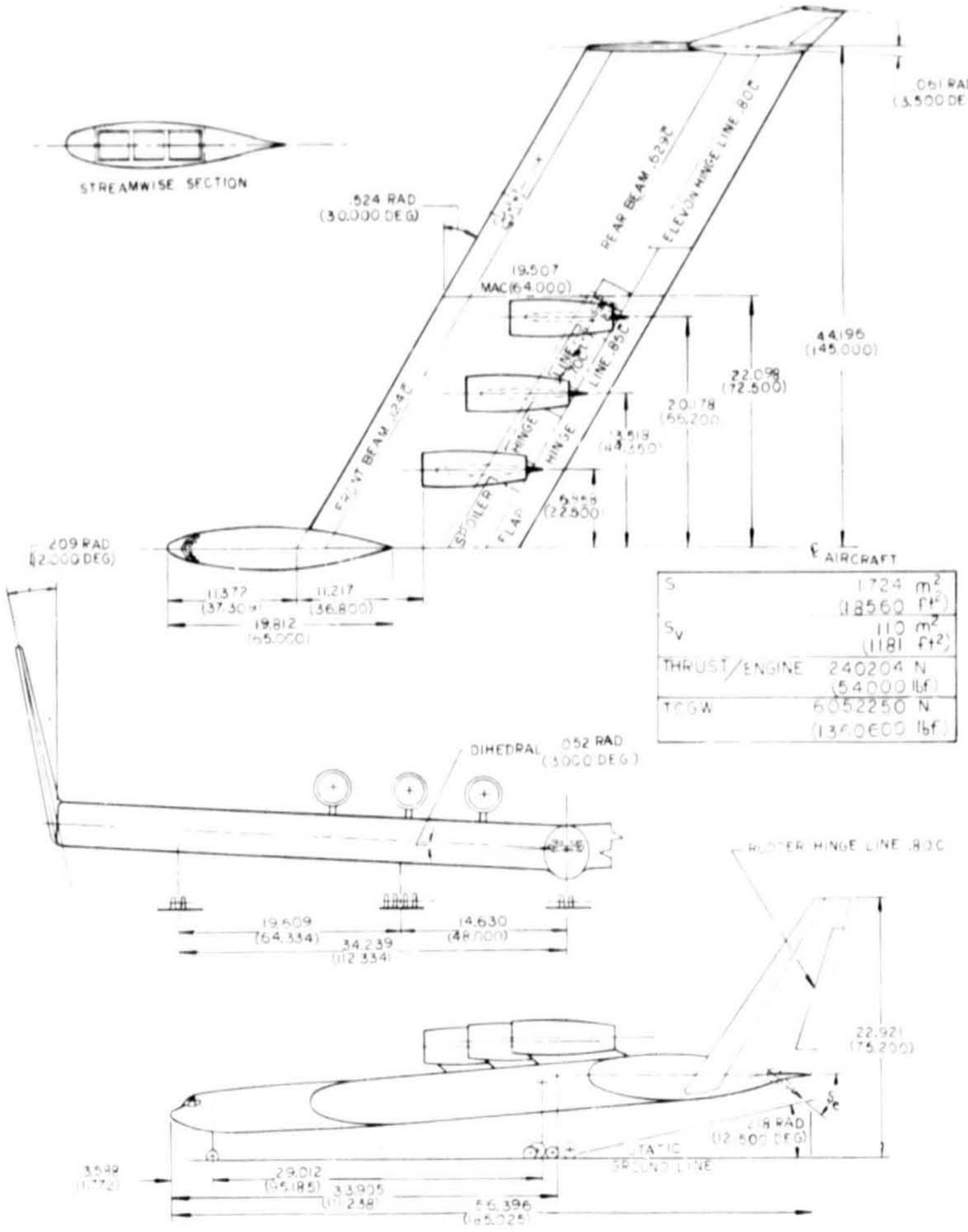
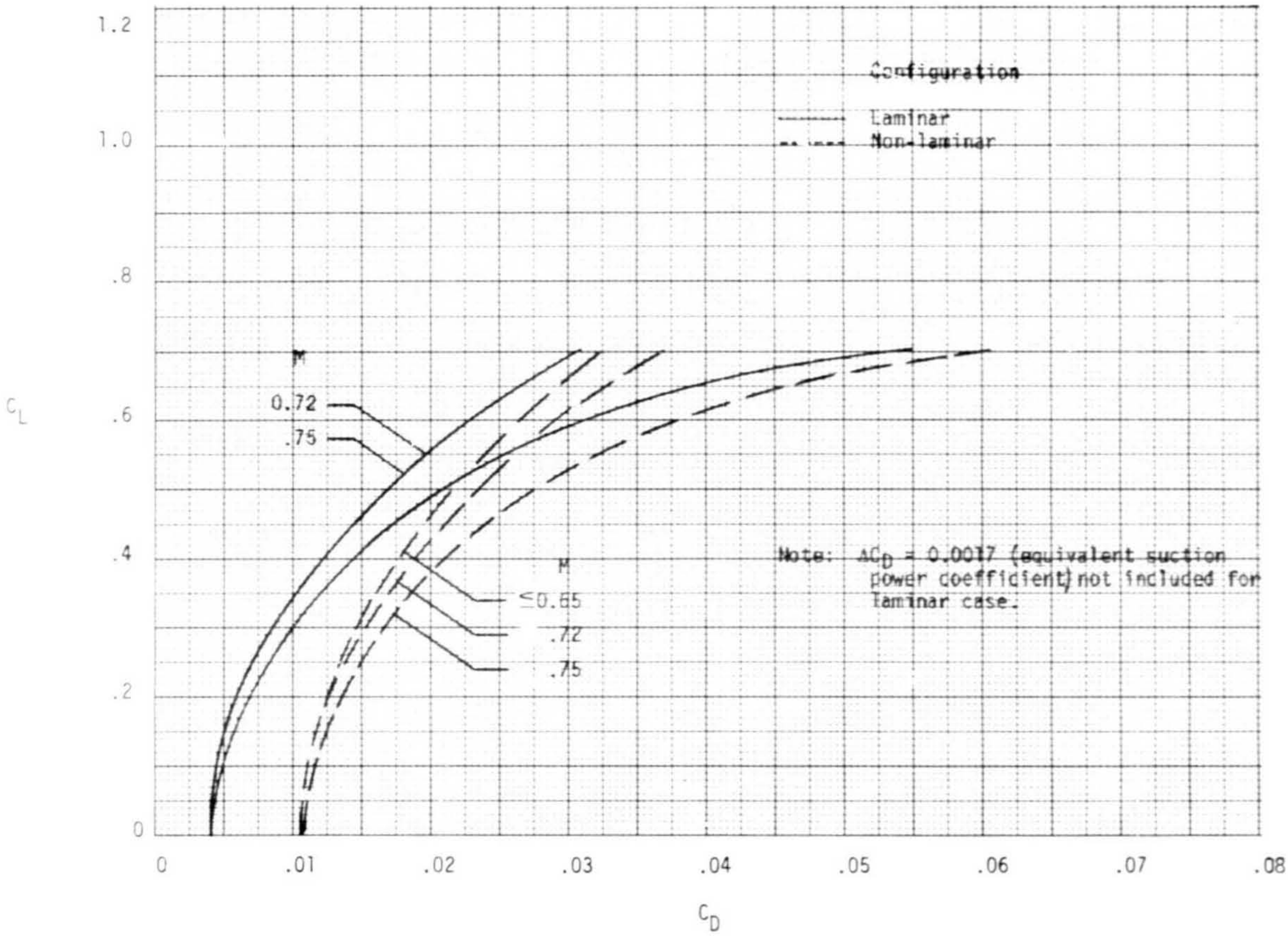
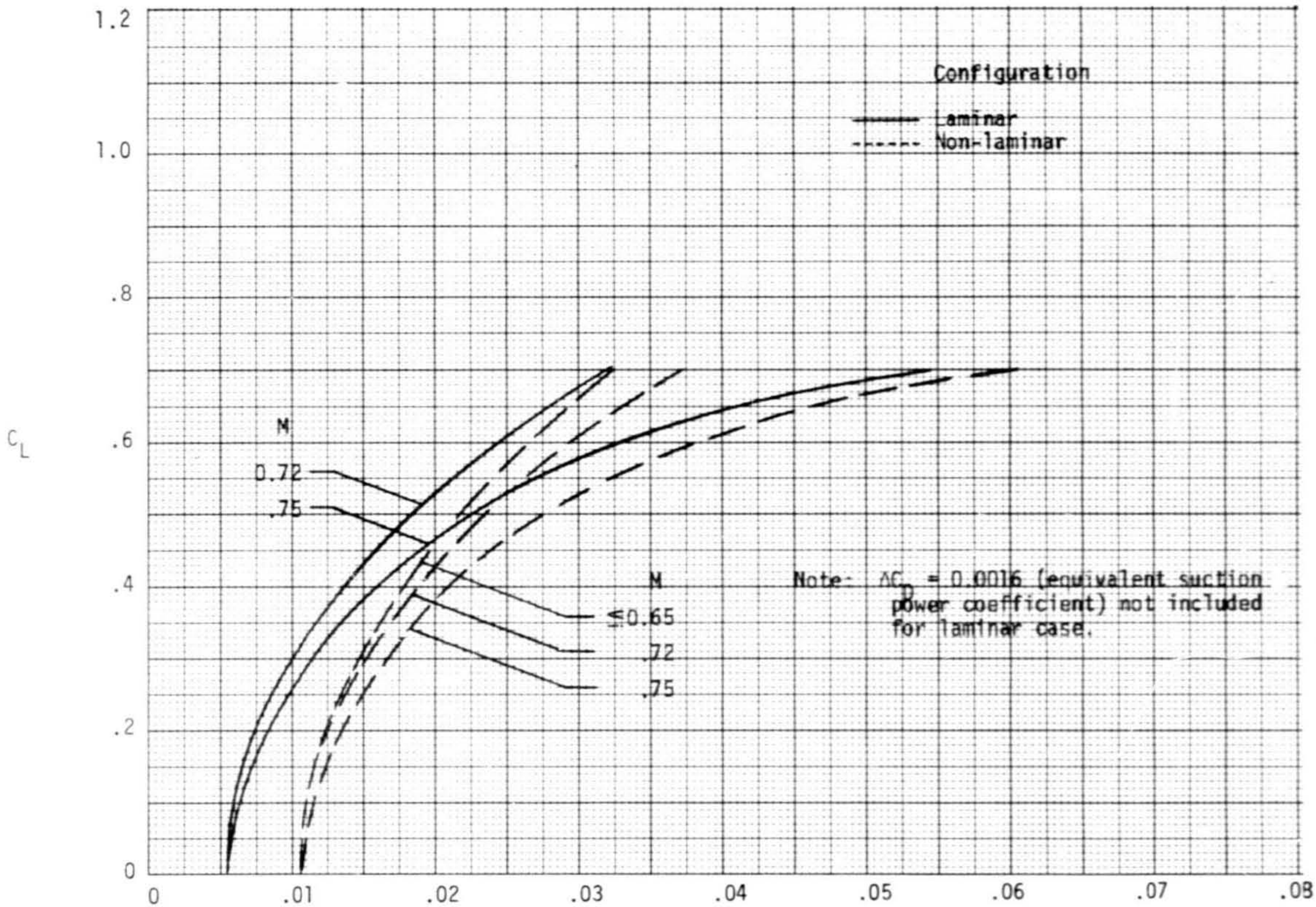


Figure 1.- Span-distributed-load cargo airplane configuration.



(a) 100 percent laminar case.

Figure 2. - Drag polars with and without laminar flow



(b) 80 percent laminar case

Figure 2. - Concluded.

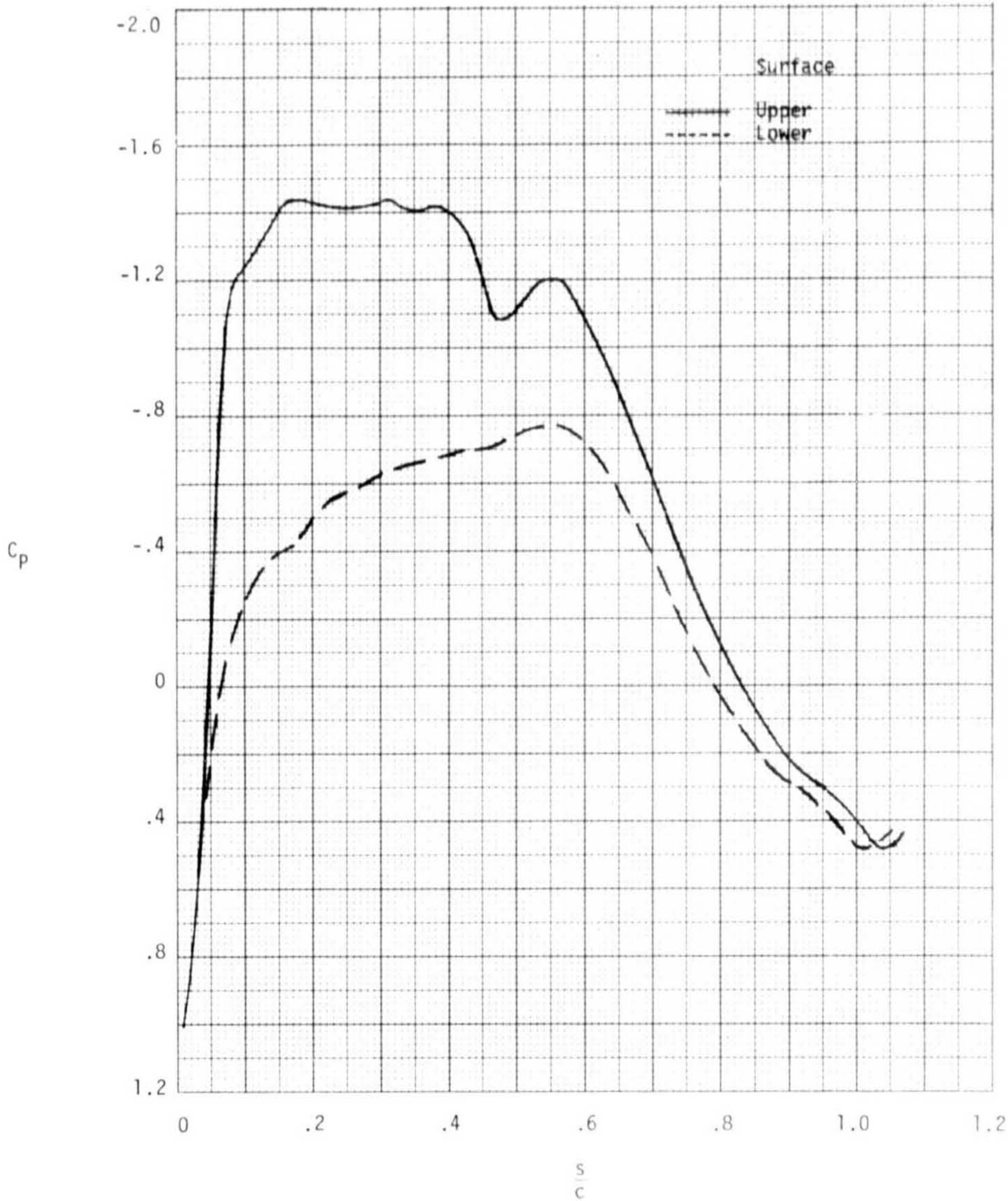


Figure 3. - Distribution of airfoil pressure coefficient

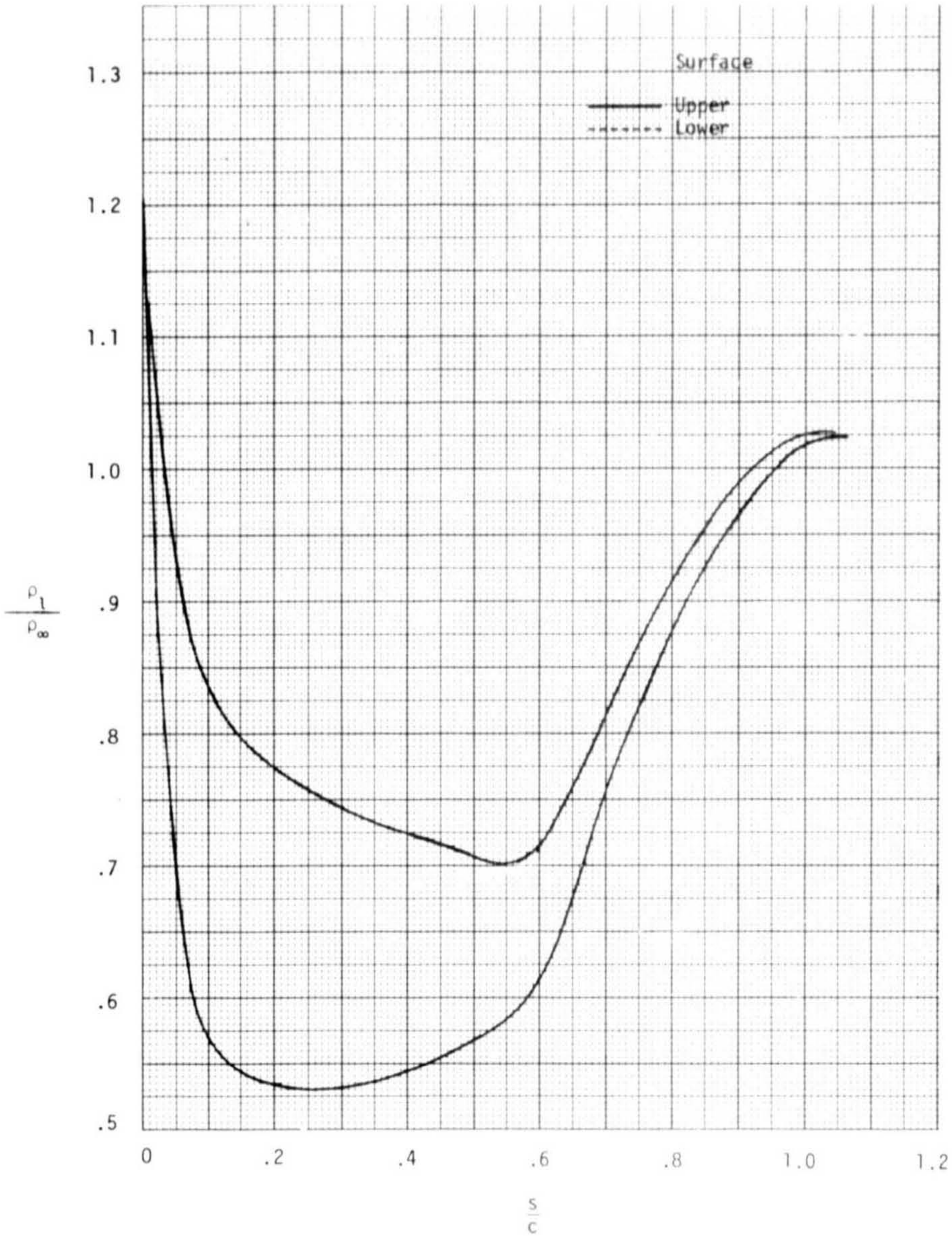


Figure 4. - Ratio of airfoil local density to that of freestream.

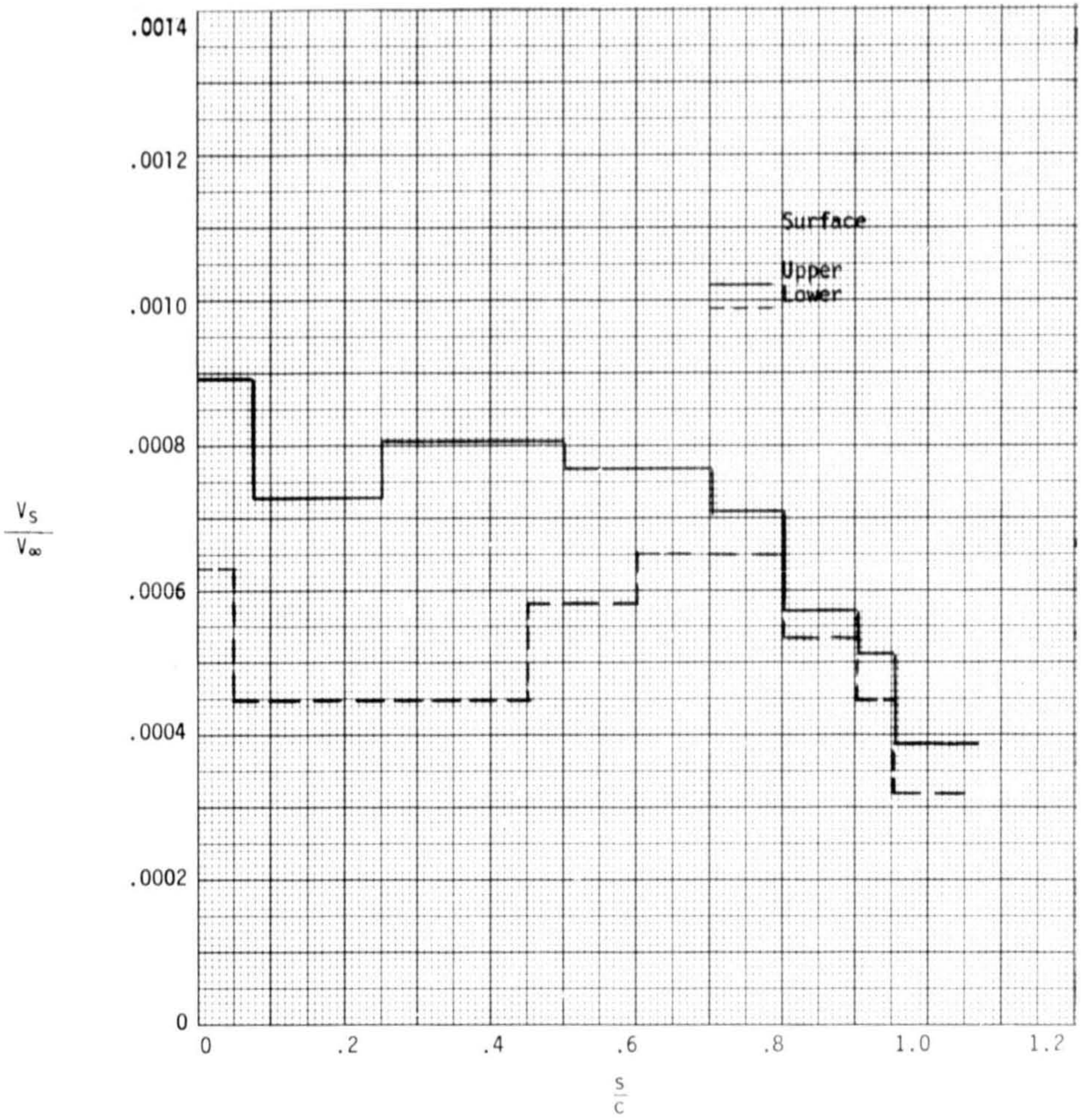


Figure 5. - Ratio of suction slot velocity to that of freestream.

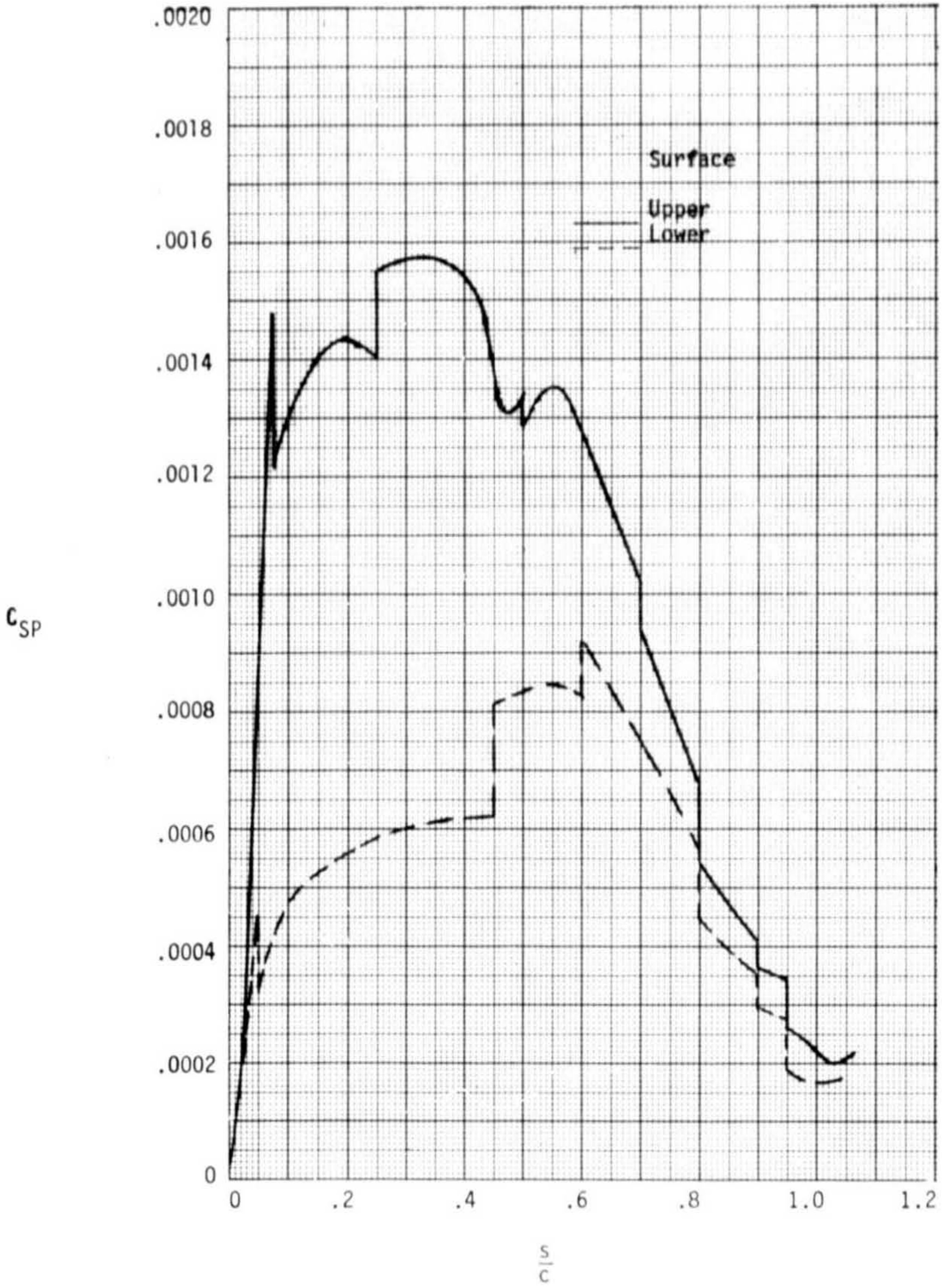
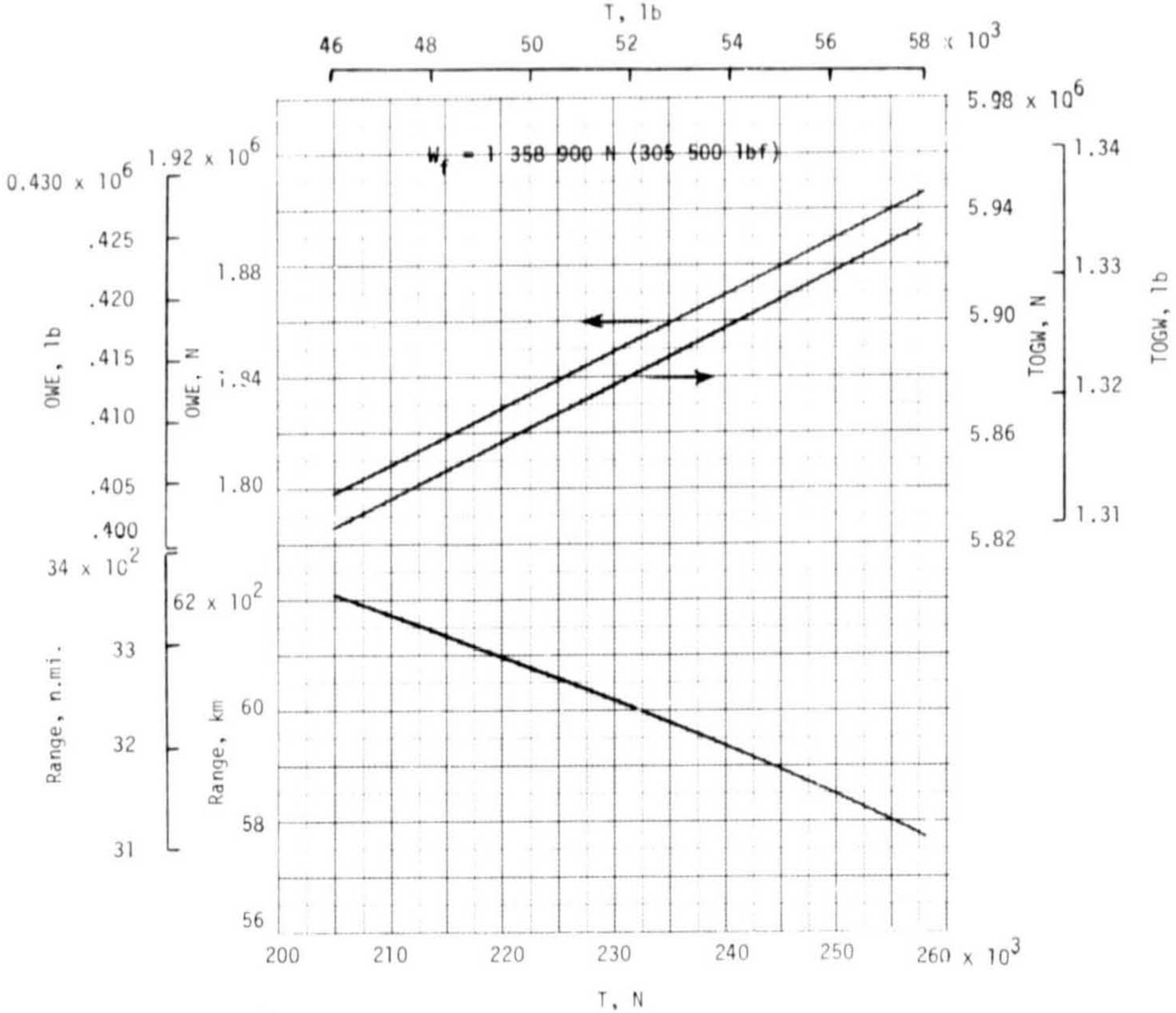
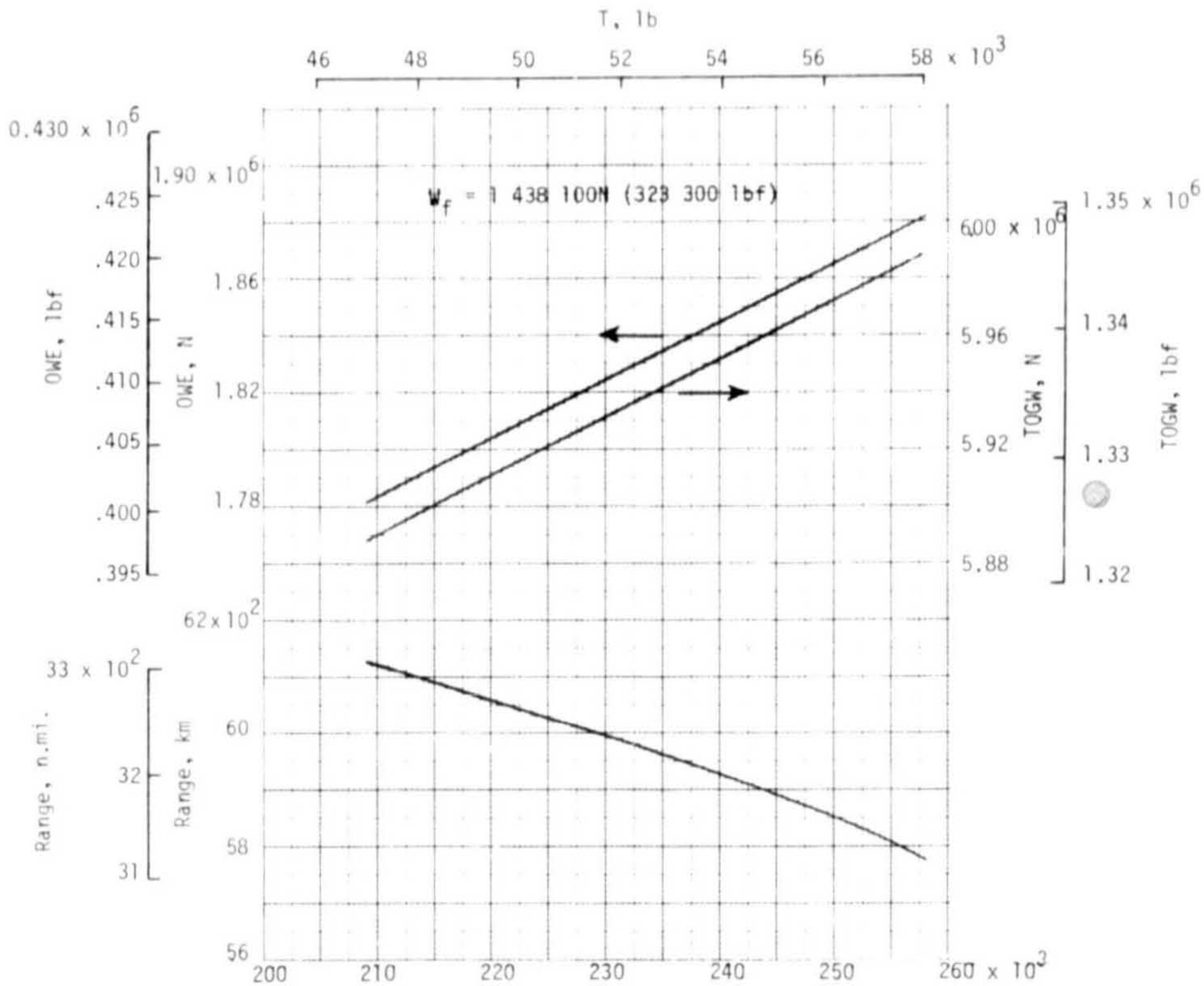


Figure 6. - Distribution of airfoil local suction power coefficient.



(a) 100 percent laminar case.

Figure 7. - Estimated effects of sea-level installed maximum static thrust per engine on OWE, TOGW, and range.



(b) 80 percent laminar case.

Figure 7. - Concluded.