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STOL TACTICAL AIRCRAFT INVESTIGATION-
EXTERNALLY BLOWN FLAP. VOLUME I.
CONFIGURATION DEFINITION. SUPPLEMENT I.
AERODYNAMIC TRADES OF FLAP AND ROLL
CONTROL SYSTEM

Dirk J. Renselaer

Rockwell International Corporation

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Volume I

Configuration Definition

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Aerodynamic Trades of Flap and Roll Control System

D. J. RENSELAER

LOS ANGELES AIRCRAFT DIVISION
ROCKWELL INTERNATIONAL CORPORATION

TECHNICAL REPORT AFFDL-TR-73-20, VOLUME I, SUPPLEMENT I

APRIL 1973

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Volume I

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APRIL 1973

i &

FOREWORD

This report was prepared for the Prototype Division of the Air Force Flight Dynamics Laboratory by the Los Angeles Aircraft Division, Rockwell International. The work was performed as part of the STOL tactical aircraft investigation program under USAF contract F33615-71-C-1760, project 643A0020. Daniel E. Fraga, AFFDL/PTA, was the Air Force program manager, and Garland S. Oates, Jr., AFFDL/PTA, was the Air Force technical manager. Marshall H. Roe was the program manager for Rockwell.

This investigation was conducted during the period from 10 June 1971 through 9 December 1972. This final report is published in six volumes and was originally published as Rockwell report NA-72-868. This report was submitted for approval on 9 December 1972.

This technical report has been reviewed and is approved.

E. J. Cross, Jr.
Lt Col, USAF
Chief, Prototype Division

ii

ABSTRACT

The basic objective of the work reported herein was to provide a broader technology base to support the development of a medium STOL Transport (MST) airplane. This work was limited to the application of the externally blown flap (EBF) powered lift concept.

The technology of EBF STOL aircraft has been investigated through analytical studies, wind tunnel testing, flight simulator testing, and design trade studies. The results obtained include development of methods for the estimation of the aerodynamic characteristics of an EBF configuration, STOL performance estimation methods, safety margins for takeoff and landing, wind tunnel investigation of the effects of varying EBF system geometry parameters, configuration definition to meet MST requirements, trade data on performance and configuration requirement variations, flight control system mechanization trade data, handling qualities characteristics, piloting procedures, and effects of applying an air cushion landing system to the MST.

From an overall assessment of study results, it is concluded that the EBF concept provides a practical means of obtaining STOL performance for an MST with relatively low risk. Some improvement in EBF performance could be achieved with further development - primarily wind tunnel testing. Further work should be done on optimization of flight controls, definition of flying qualities requirements, and development of piloting procedures. Considerable work must be done in the area of structural design criteria relative to the effects of engine exhaust impingement on the wing and flap structure.

This report is arranged in six volumes:

Volume I   - Configuration Definition

Volume II   - Design Compendium

Volume III - Performance Methods and Takeoff and Landing Rules

Volume IV   - Analysis of Wind Tunnel Data

Volume V   - Flight Control Technology

    Part I   - Control System Mechanization Trade Studies
    Part II   - Simulation Studies/Flight Control System Validation
    Part III - Stability and Control Derivative Accuracy
              Requirements and Effects of Augmentation System Design

Volume VI   - Air Cushion Landing System Trade Study

This supplement to Volume I is generated to provide the aerodynamic data needed to make a design choice between double and triple slotted flaps and between a roll control system with BLC or without BLC for the baseline configuration definition in Volume I. The study in this report is based on a comparison of minimum speeds at which safety, stability and control, and performance criteria are met. Results show that the minimum speed for triple slotted flaps is limited by the relatively smaller roll control capability and is about 3 knots higher than the minimum speed for double slotted flaps. Using BLC can reduce the minimum speed by approximately 5 knots for the same engine exhaust thrust. If the engine thrust is reduced because of bleed air extraction the benefit of BLC becomes less, and its application becomes questionable.

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From an overall assessment of study results, it is concluded that the EBF concept provides a practical means of obtaining STOL performance for an MST with relatively low risk.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
STOL Transport						
Externally Blown Flaps						
Medium STOL Transport						
Roll Control						
Flap Design						

TABLE OF CONTENTS

TABLE OF CONTENTS - Concluded

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - Cont.

LIST OF SYMBOLS

AEO	All engines operating
R	Aspect ratio
b	Wing span, feet
BLC	Boundary layer control
$\bar{c}$	Wing mean aerodynamic chord, feet
C_D	Drag coefficient (may include thrust effects), D/qS. If negative the power effects yield a net forward force
CEF	Critical engine failed
c.g.	Center of gravity
C_L	Lift coefficient (may include thrust effects), L/qS
C_{LTRIM}	Trimmed lift coefficient
C_m	Pitching moment coefficient
C_n	Yawing moment coefficient
c.p.	Center of pressure
C_T	Thrust coefficient T/qS, where T is the static thrust at the engine exhaust nozzle
ΔC_ℓ	Increment in rolling moment coefficient
C_μ	Blowing coefficient, same as C_T for external blowing
$C_{\mu BLC}$	Blowing coefficient from BLC, $(\dot{m}v)_{BLC}/qS$ where $(\dot{m}v)_{BLC}$ is the exhaust force at the BLC nozzle
$C_{\mu AIL}$	Blowing coefficient from aileron BLC, same as $C_{\mu BLC}$
D	Aircraft drag (may include thrust effects), pounds
DLC	Direct lift control
ΔF_x	Change in forward force, pounds

LIST OF SYMBOLS - Cont.

g	Gravitational constant, ft/sec^2
IGE	In ground effect
i_H	Stabilizer setting, degrees
I_{xx}	Moment of inertia in roll, pounds $ft\text{-}sec^2$
L	Aircraft lift, pounds
$\mathcal{L}$	Rolling moment, foot pounds
ℓ_H	Tail length to horizontal tail, feet
ℓ_v	Tail length to vertical tail, feet
M	Pitching moment, nose up positive, foot pounds
MAC	Mean aerodynamic chord, same as $\bar{c}$, feet
n	Normal acceleration, ft/sec^2
$\mathcal{N}$	Yawing moment, foot pounds
OGE	Out of ground effect
q	Dynamic pressure, $pounds/foot^2$
S	Wing reference area, $feet^2$
T	Engine thrust at exhaust nozzle in static condition, pounds
t	Time, seconds
V	Aircraft speed, knots
V_{min}	Minimum aircraft speed or stall speed, knots
V_s	Stall speed, knots
W	Aircraft gross weight, pounds
Y_T	Side force on the vertical tail, pounds

LIST OF SYMBOLS - Concluded

Z_V Distance of center of pressure of vertical tail above aircraft c.g. in stability axis system, feet

δ_a Aileron deflection, degrees

δ_F Flap angle, degrees

δ_j Deflection of BLC exhaust nozzle, degrees

δ_{sp} Spoiler deflection, degrees

α Angle of attack, degrees

Λ Sweep angle of wing quarter chord line, degrees

ϕ Bank angle, degrees

γ Climb angle, degrees

Δ Difference

τ_R Roll time constant, seconds

SUBSCRIPTS

AV	Average
BLC	Due to BLC
EF	Due to engine failure
MAX	Maximum
NT	Tail Off (no tail)
P	Due to power effects
PE	Per engine
PO	Power off
SP	Due to spoilers
WT	With tail

Section I

INTRODUCTION

As part of the design refinement of the MST - TAI baseline configuration, a study was needed of the aerodynamic aspects entering into the choice between double and triple slotted flaps and the use of BLC for roll control. Triple slotted flaps allow a larger chordwise extension of the flap and thus a greater L/D ratio. On the other hand, triple slotted flaps are less suitable for BLC aided roll control. They also decrease the effectiveness of spoiler roll control systems. To determine which flap system represents an optimum aerodynamically, minimum speeds are compared on the basis of a climb criterion, some roll acceleration criteria, and a lift loss criterion. The geometry that allows the lowest speed is considered the optimum in this report; the impact of the geometry on aircraft structural weight and complexity is beyond the scope of this document.

The following geometries are considered:

1. Full span double slotted flaps, no BLC
2. Inboard double slotted flaps, outboard single slotted flaps with BLC
3. Full span triple slotted flaps, no BLC
4. Inboard triple slotted flaps, outboard single slotted flaps with BLC.

1

Section II

SUMMARY

In this document data were analyzed to aid in a selection of the wing flap system and roll control system for a medium STOL transport study. A sketch of the transport is sh:·m in Figure 1. Specifically, a comparison of double and triple slotted flaps has been made for the purpose to select an optimum flap system on the basis of the best STOL speed and STOL lifting capability. Also, data are given for the selection of associated roll control systems. In conjunction with this, spoilers and full span flaps are considered, as well as partial span flaps together with boundary layer control on deflected single slotted surfaces at the wing tips. Flap geometries and spoiler geometries used are presented in Figures 2 through 5.

The comparison is made here based on aerodynamic characteristics only. The impact of BLC bleed air or gas extraction from the engines on the aircraft weight, as well as the effect of the flap and control system selection on the aircraft weight is beyond the scope of this document.

Various criteria are used for the selection of the recommended geometry. These are:

1. The minimum speed or the maximum lifting capability at which it is possible to climb along a 3-degree climb path with the critical engine inoperative and with the flap angle such that n can be 1.3 with all engines operating, and $V = 1.1 V_{min}$ with one engine failed (both out of ground effect).

2. The minimum speed at which the roll acceleration requirements are met with all engines operating (Level 1).

3. The minimum speed at which the roll acceleration requirements are met with the critical engine inoperative (Level 3).

4. The minimum speed at which the lift loss due to ground effect together with the lift loss due to the roll control input associated with the Level 1 requirement is not greater than 12.5 percent in the landing configuration with a maximum positive lift increment from DLC.

3

SPOILER NO. 1
NO. 2
NO. 3
NO. 4
NO. 5

0.250 C
24°
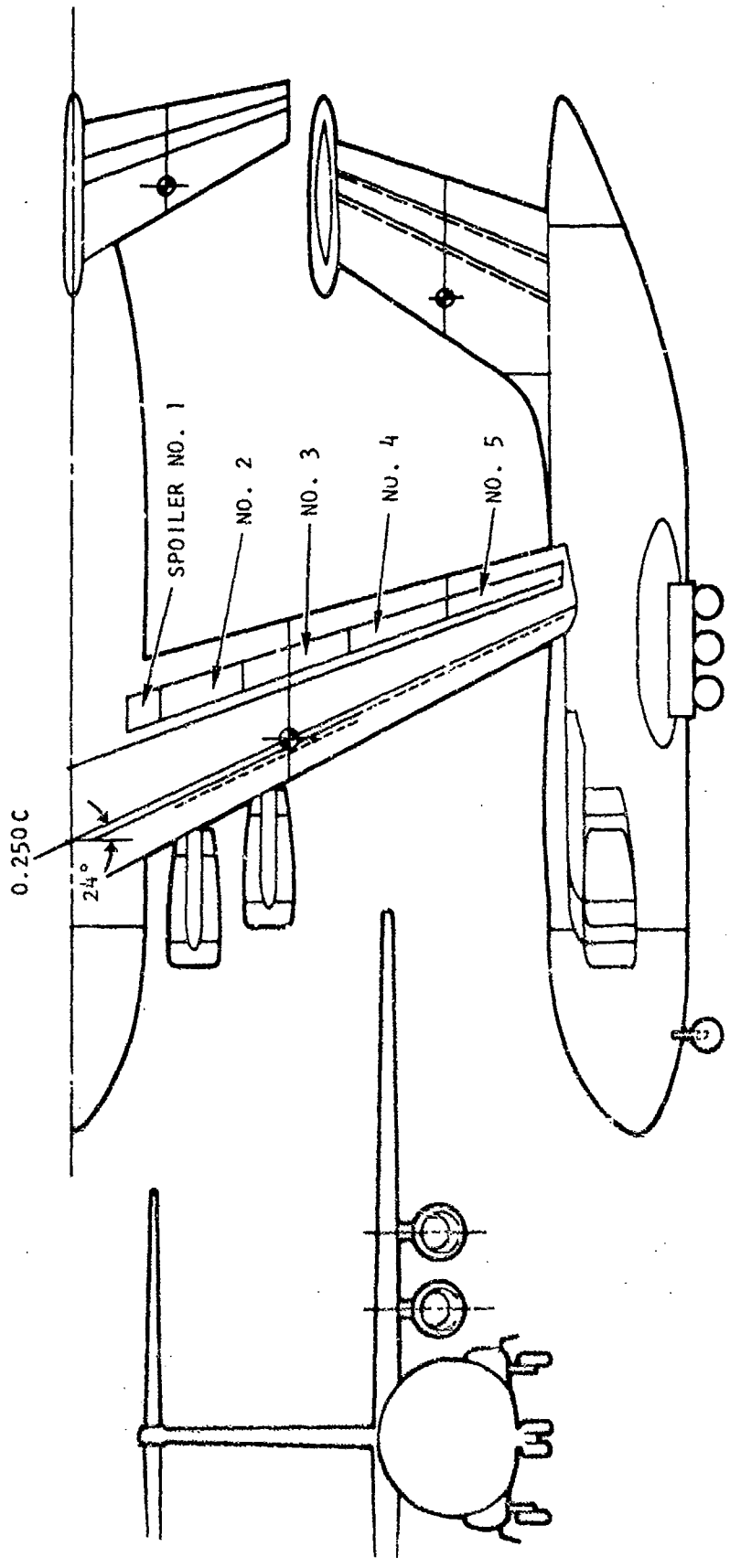
AR 7, Λ = 24° WING

Figure 1. Side-View STOL Transport Wind Tunnel Model

4
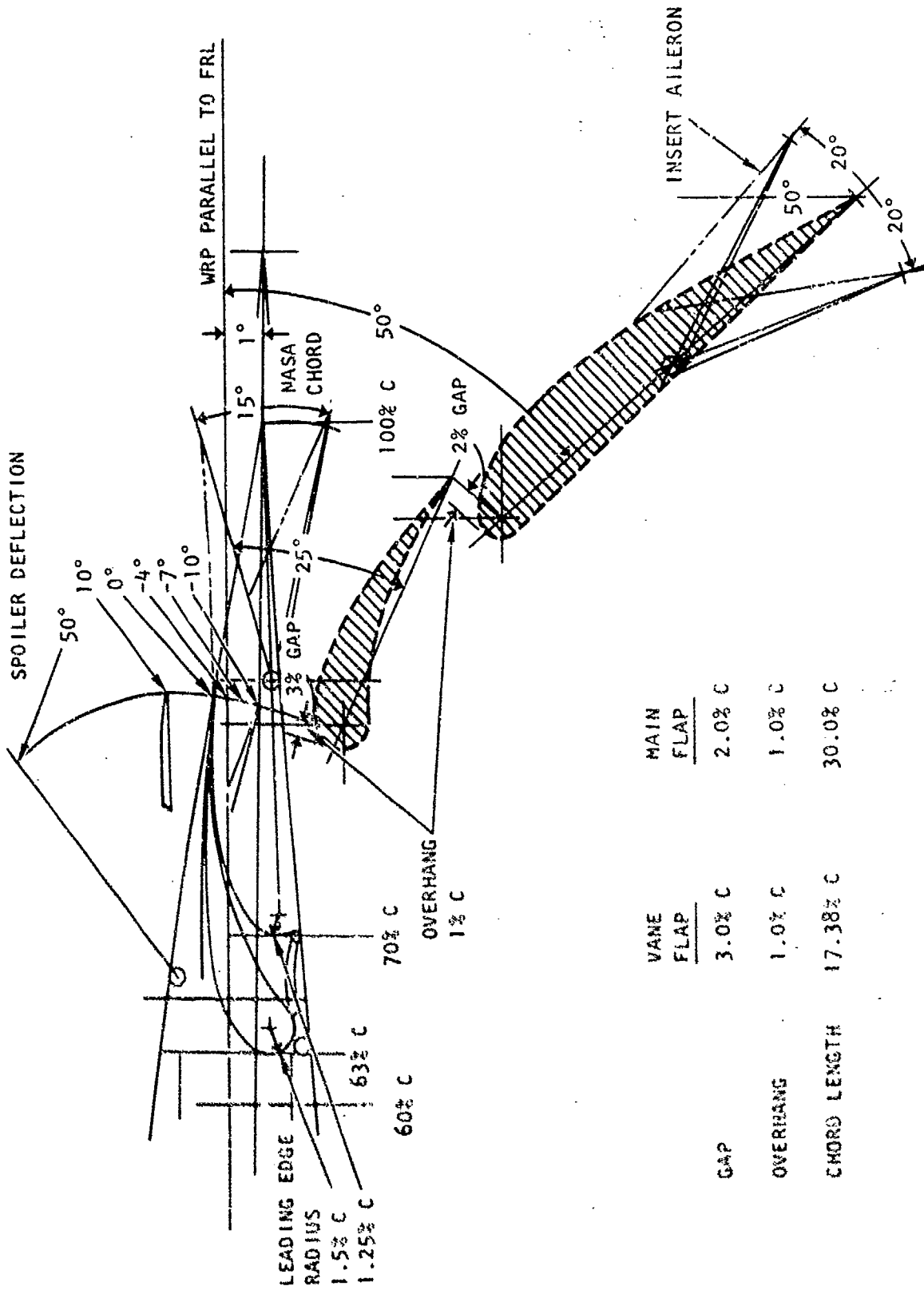
Figure 2. Outboard Wing Flap - Double-Slotted - MST Wind Tunnel Model

	VANE FLAP	MAIN FLAP
GAP	3.0% C	2.0% C
OVERHANG	1.0% C	1.0% C
CHORD LENGTH	17.38% C	30.0% C

SPOILER DEFLECTION

50°
10°
0°
-4°
-7°
-10°

LEADING EDGE
RADIUS
1.5% C
1.25% C

60% C
63% C
70% C

OVERHANG
1% C

3% GAP
25°

WRP PARALLEL TO FRL

15° 1°

NASA
CHORD

100% C
50°

2% GAP

INSERT AILERON

50°
20°
20°
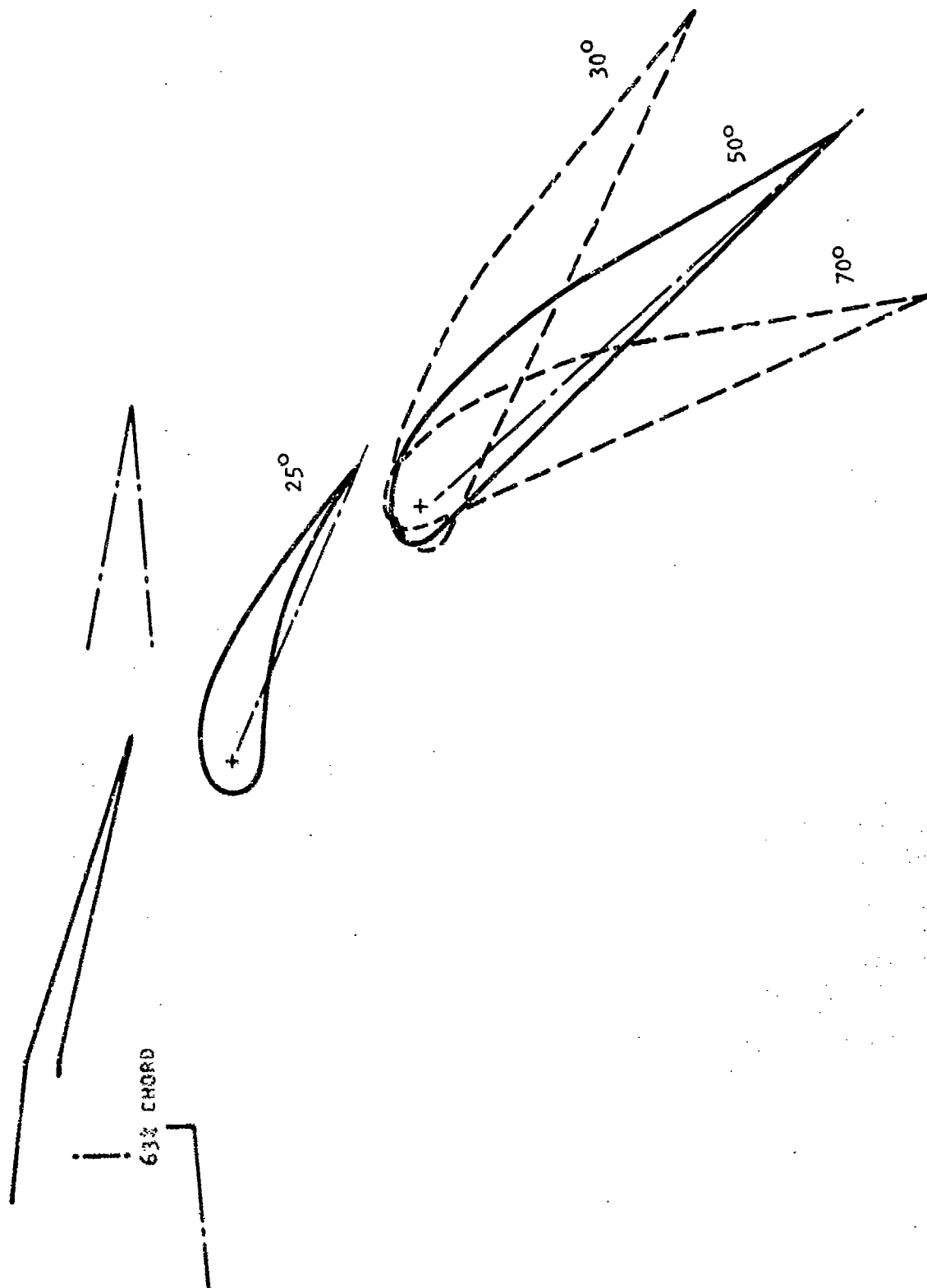
Figure 3. Inboard Double-Slotted Flap

63% CHORD

25°

30°

50°

70°

Figure 4. Outboard Wing Flap – Triple-Slotted – MST Wind Tunnel Model
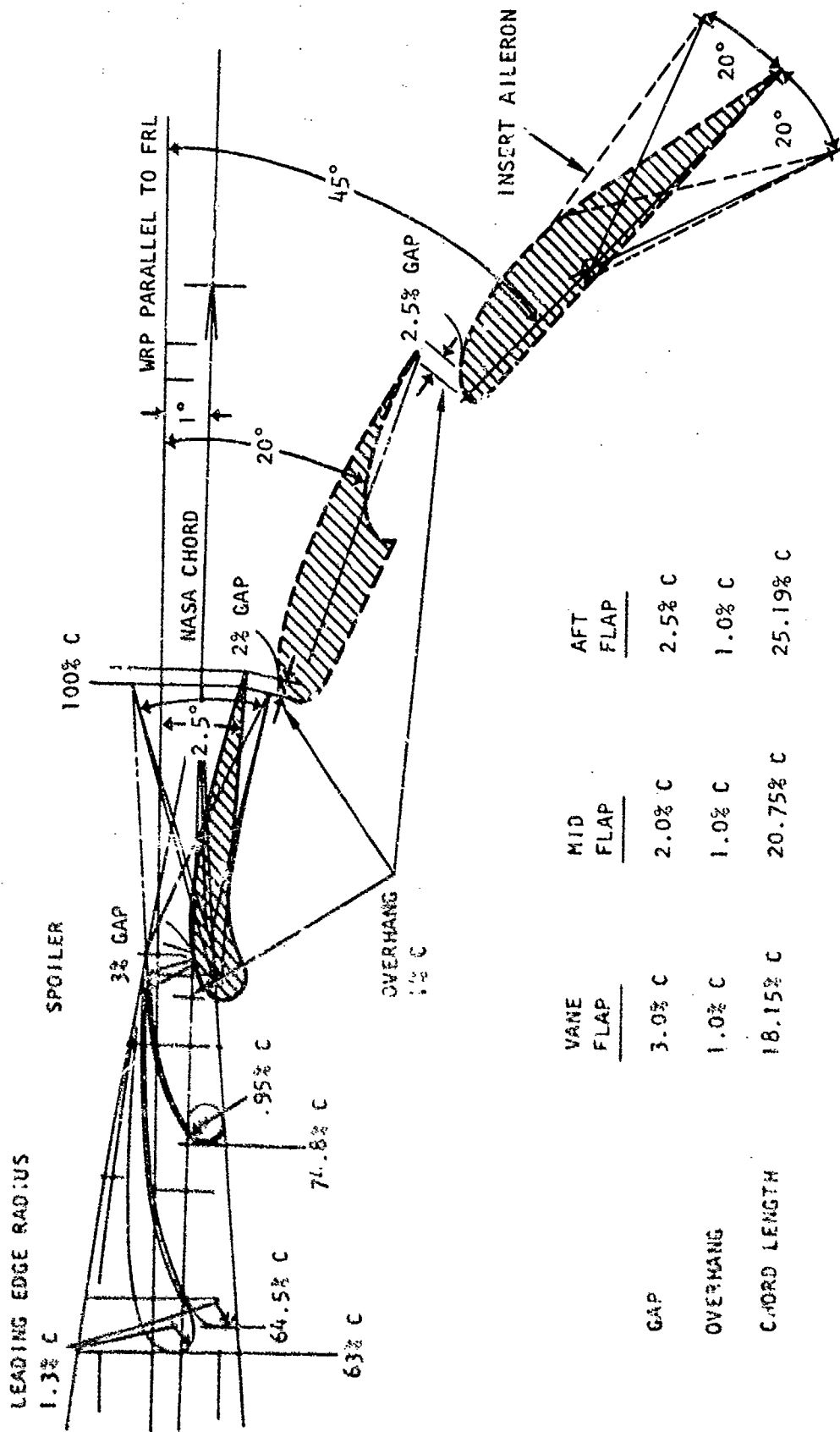
	VANE FLAP	MID FLAP	AFT FLAP
GAP	3.0% C	2.0% C	2.5% C
OVERHANG	1.0% C	1.0% C	1.0% C
CHORD LENGTH	18.15% C	20.75% C	25.19% C

63% CHORD

2.5°

30°

35°

55°

75°
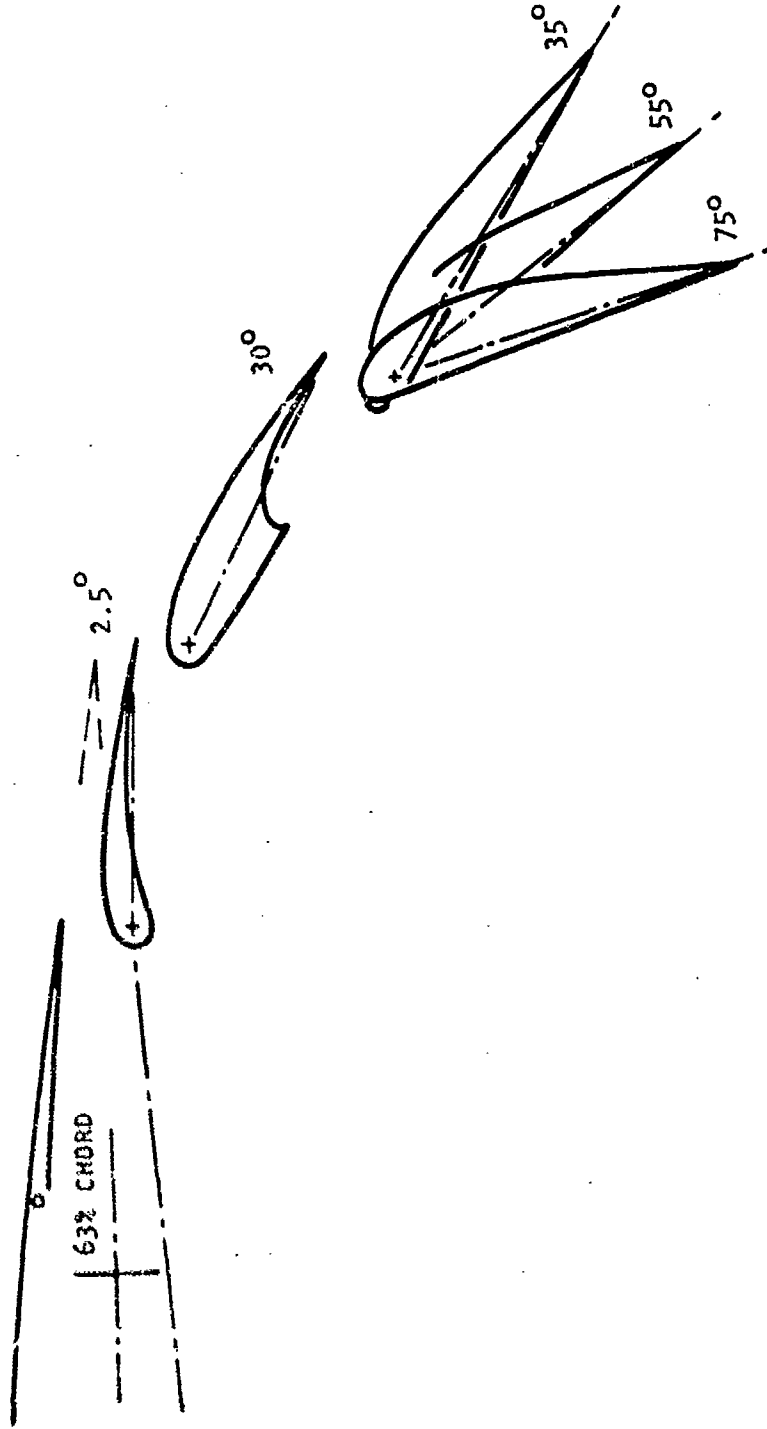
Figure 5. Inboard Triple-Slotted Flap

9

If the lift loss quoted in the last item is maintained during one second, the aircraft sink speed increases approximately four ft/second. This implies that, if the aircraft at first descends along a flight path with six feet/second, full roll control during one second prior to touch-down will increase the sink rate to 10 feet/second. Full roll control during one second will change the bank angle approximately 10 degrees. This is an input expected to be made relatively often near the ground.

The comparison of speeds at which the above four criteria are satisfied is given in Figure 6 for the various geometries considered. The largest speed of each of the criteria should be used within each of the geometries. These speeds should then be compared with each other and the geometry giving the lowest of those speeds is aerodynamically the best.

It is seen that the combination of the partial span double slotted flap with a single slotted BLC aileron at the tip yields the lowest speed, i.e., 74 knots for a sample value of W/S = 80 and T/W = .55.

Second in line is the part span triple slotted flap with 77 knots, having also BLC at the tip. However, it should be noted that in case the roll control power for this triple slotted flap is somewhat larger than estimated, or if the flow through a flap gap can be manipulated together with the roll control spoiler actuation, the speed for this flap configuration can be reduced to 72 knots. The roll control data with the triple slotted flap are based on only a single wind tunnel test run, and improvement may be possible.

Both of these flap/control geometries make use of aileron BLC. This BLC is not only beneficial from a standpoint of roll control, but also the lift/drag relation in the climbout is improved. The figure shows that this results in speed decreases in the order of 5 knots if only the climbout criterion is considered. However, the increase in engine weight to provide the energy for BLC must be considered in addition.

The above listed criterion (1) can also be expressed in terms of the required T/W ratio, where T is the total static exhaust thrust used for external blowing. At the sample value of W/S = 80, and using V = 80

9
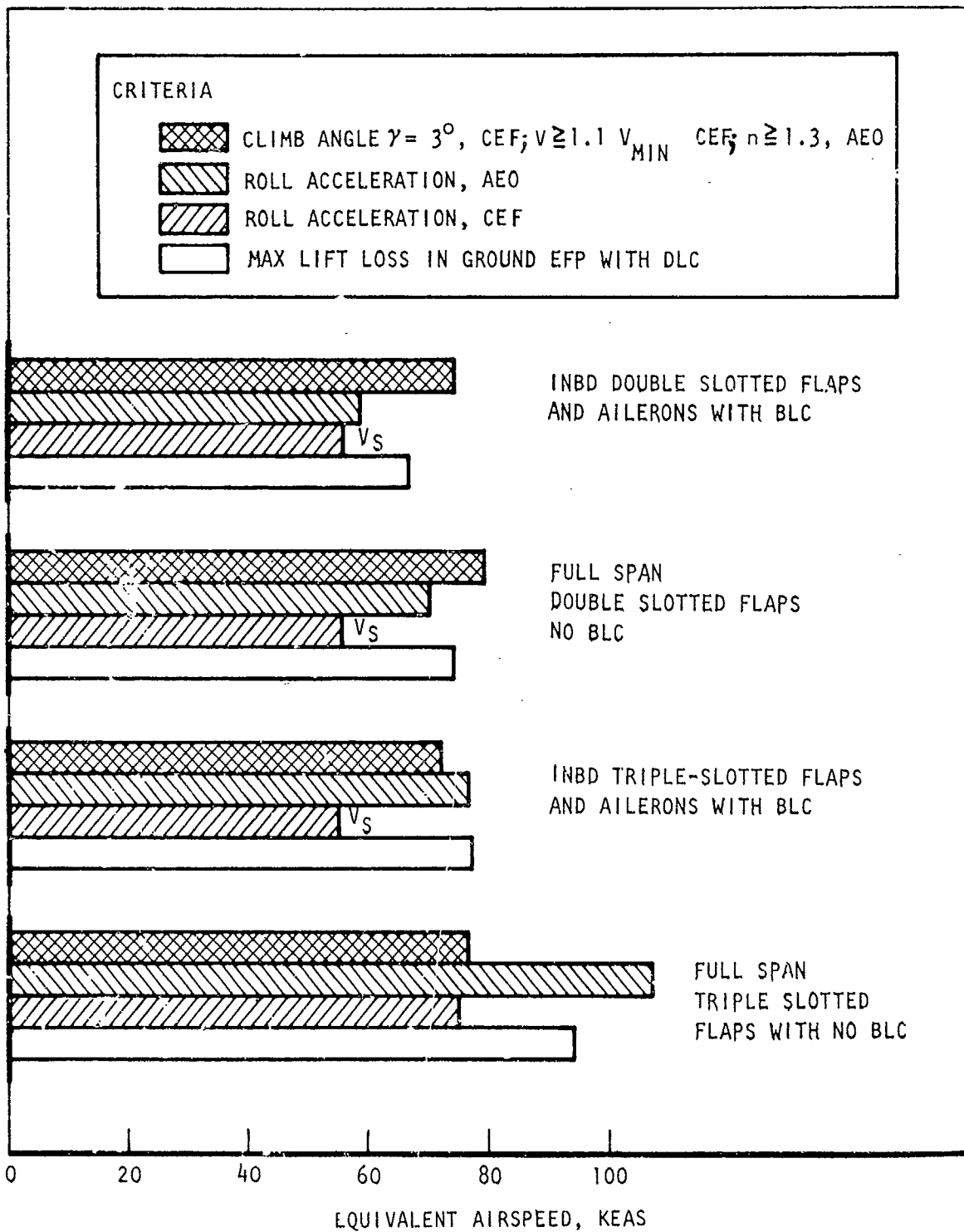
Figure 6. Comparison of Minimum STOL Speeds for Double - and Triple-Slotted Flaps, With and Without BLC

10

knots (EAS), the comparison becomes:

Aileron	Flaps	
BLC	Double Slotted	Triple Slotted
Without BLC (Full Span Flaps)	$\frac{T}{W} = .550$	$\frac{T}{W} = .516$
With BLC (Partial Span Flaps)	$\frac{T}{W} = .472$	$\frac{T}{W} = .452$

More detailed discussions and the methods used in determining the speeds and the lifting capabilities are given in the following subsequent sections:

Section III - Comparison of Climb Speeds
Section IV - Comparison of Roll Acceleration with All Engines Operating
Section V   - Comparison of Roll Acceleration with One Engine Inoperative
Section VI - Comparison of Lift Loss Due to Maximum Roll Control

It should be noted that the above comparisons are made to obtain an impression of relative magnitudes. The actual average level of the climbout speeds and lift capability may be somewhat different when other safety speed and maneuver margins are considered in addition to those taken here. Additional margins may be those related to ground effect.

11
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Section III

COMPARISON OF CLIMB SPEEDS

3.1 TRIMMED LIFT AND SPEED RELATIONSHIP FOR CLIMB

The purpose of this section is to establish the merits of triple slotted flaps versus double slotted flaps, and to establish the benefits of aileron BLC on the basis of aerodynamic STOL takeoff climb performance. Other aerodynamic criteria for selection are discussed in other sections.

The criterion for STOL climb performance used in the present section is the minimum speed or highest lifting capability existing at which it is possible to climb with a three-degree flight path angle with one engine inoperative, except as limited by speed and maneuver margins for flight safety. The maneuver margin used is $n = 1.3$ with all engines operating, and a speed margin of 10 percent with one engine inoperative, both out of ground effect. Other safety margins in terms of speed, angle of attack, or maneuver capability with all engines operating or with one engine inoperative in or out of ground effect may at times be more critical, but are not considered in the present report because they were not adequately firmed up at the time of this study.

Trimmed data for a c.g. location of 25 percent MAC and with all engines operating (AEO) and with the critical engine failed (CEF) on which the present comparisons are based are presented in Figures 7 through 18. These figures show the total aircraft lift L as a function of the total aircraft drag D for various speed conditions, each nondimensionalized (or "normalized") by the engine nozzle exhaust thrust per engine, T_{PE}. The value of D includes the thrust effects, and if D is negative a net forward force exists. The speed condition is expressed in terms of the inverse of the blowing coefficient $1/C_{\mu PE}$ or $q/(T_{PE}/S)$ in which q is the dynamic pressure and S is the wing area.
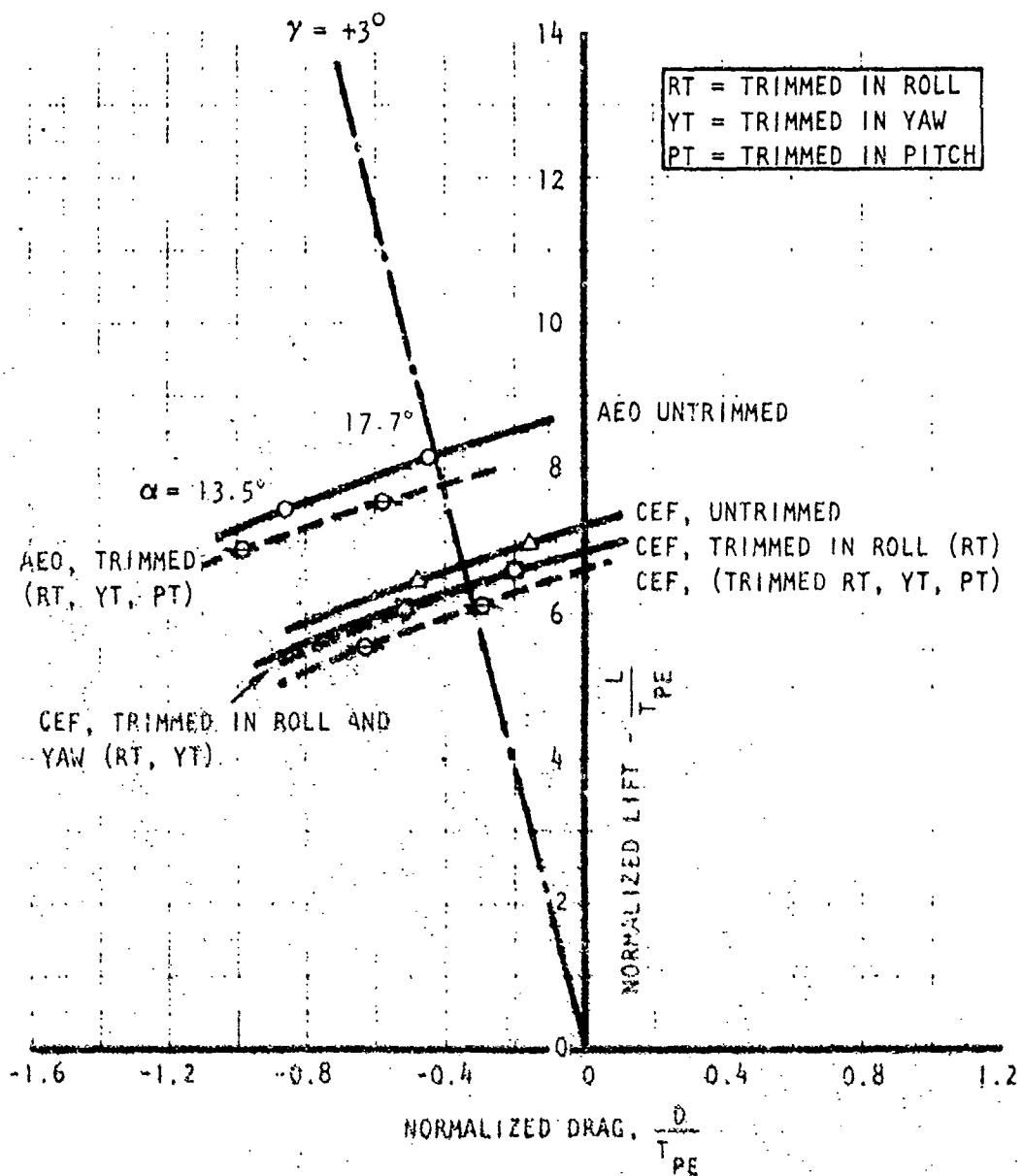
Figure 7. Full-Span, Double-Slotted Flaps

14

$$\delta_F = 25°/30°$$

NO AILERON BLC

$$C_{\mu PE} = 0.50 \qquad \frac{q}{T_{PE}/S} = 2.00$$
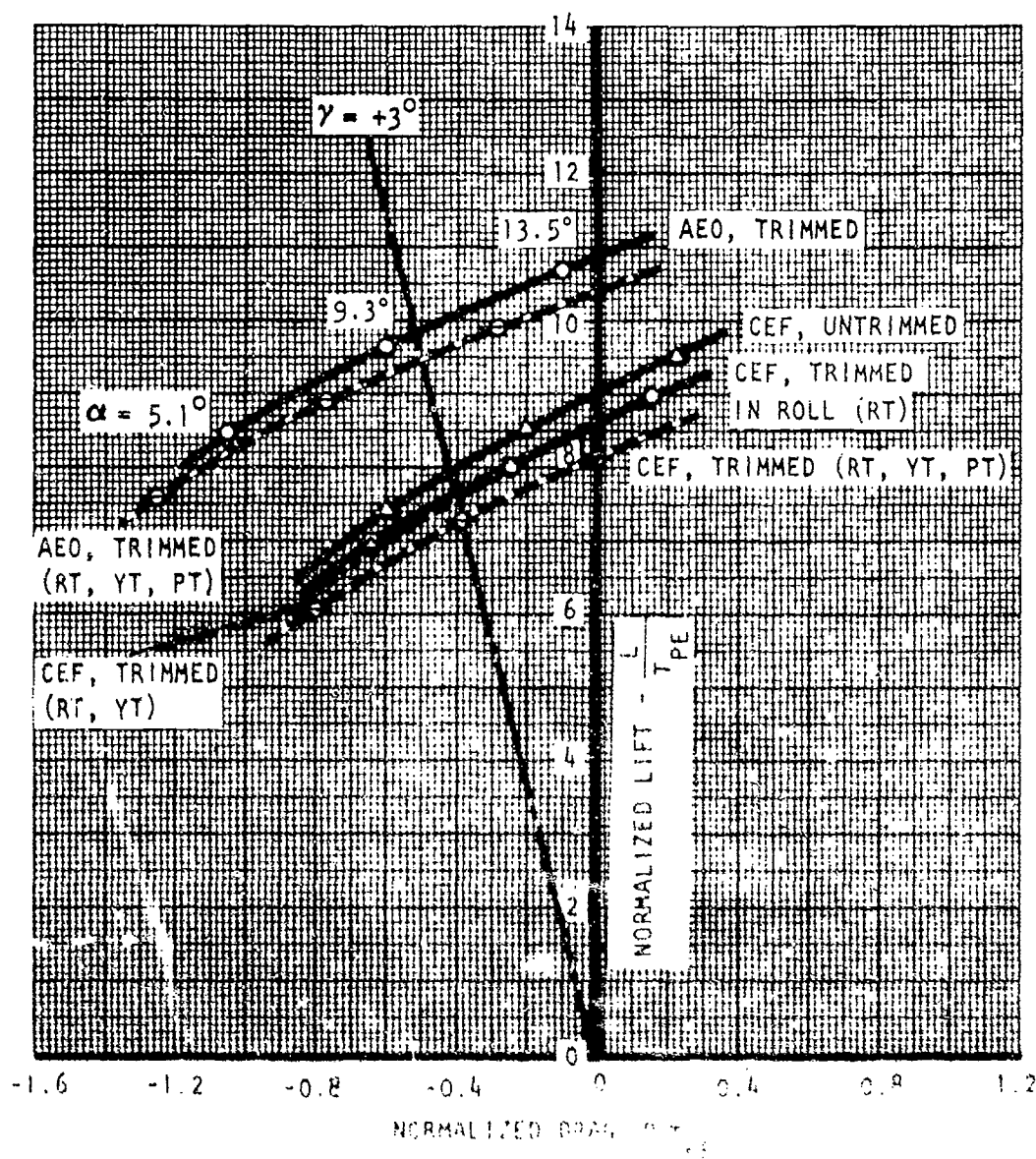
Figure 8. Full Span, Double-Slotted Flaps

$$\delta_F = 25^\circ/50^\circ$$

NO AILERON BLC
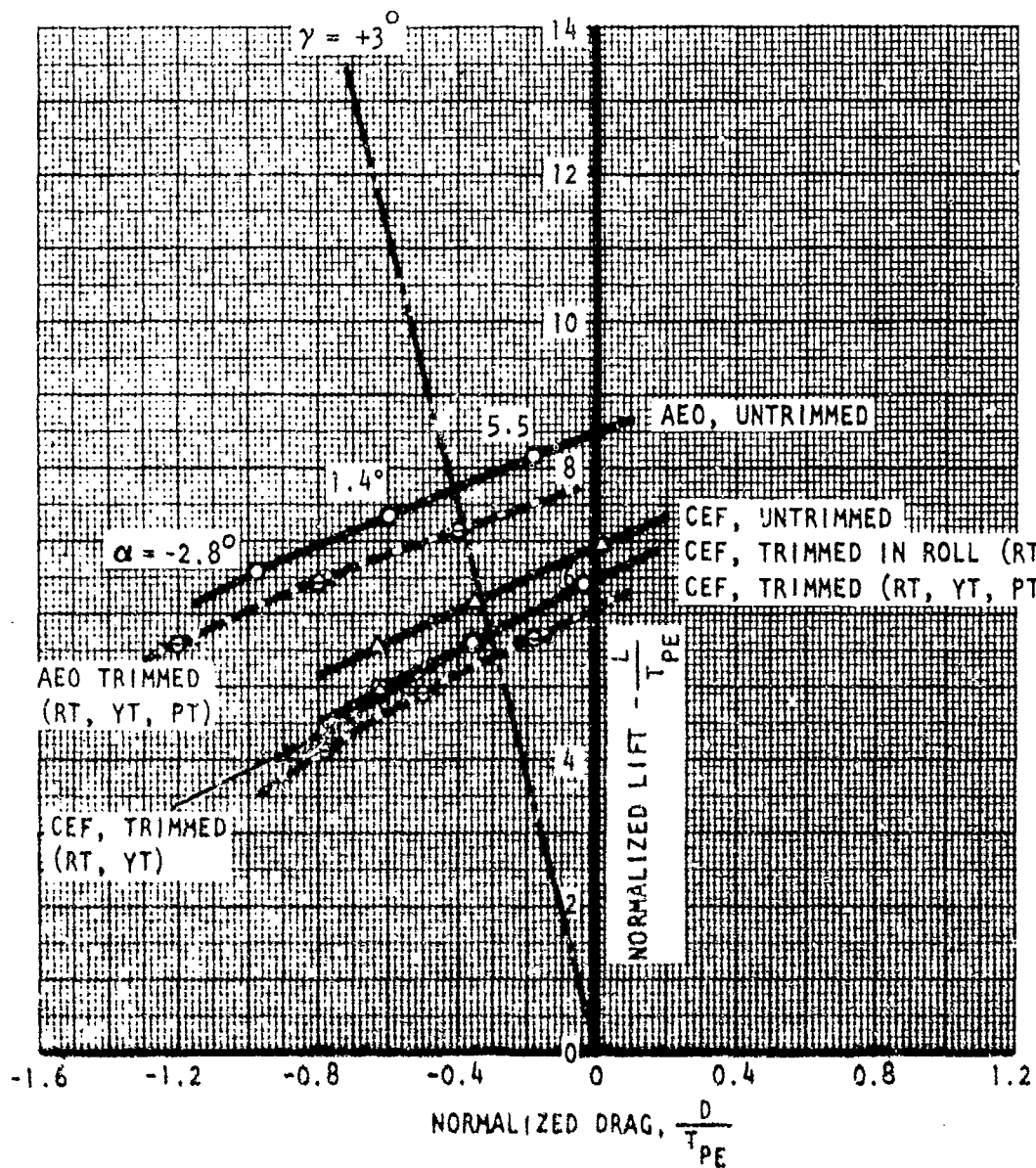
$$\boxed{C_{\mu_{PE}} = 0.825} \quad \frac{q}{T_{PE}/S} = 1.21$$

Figure 9. Full-Span, Double-Slotted Flaps

$\delta_F = 25^\circ/50^\circ$

NO AILERON BLC
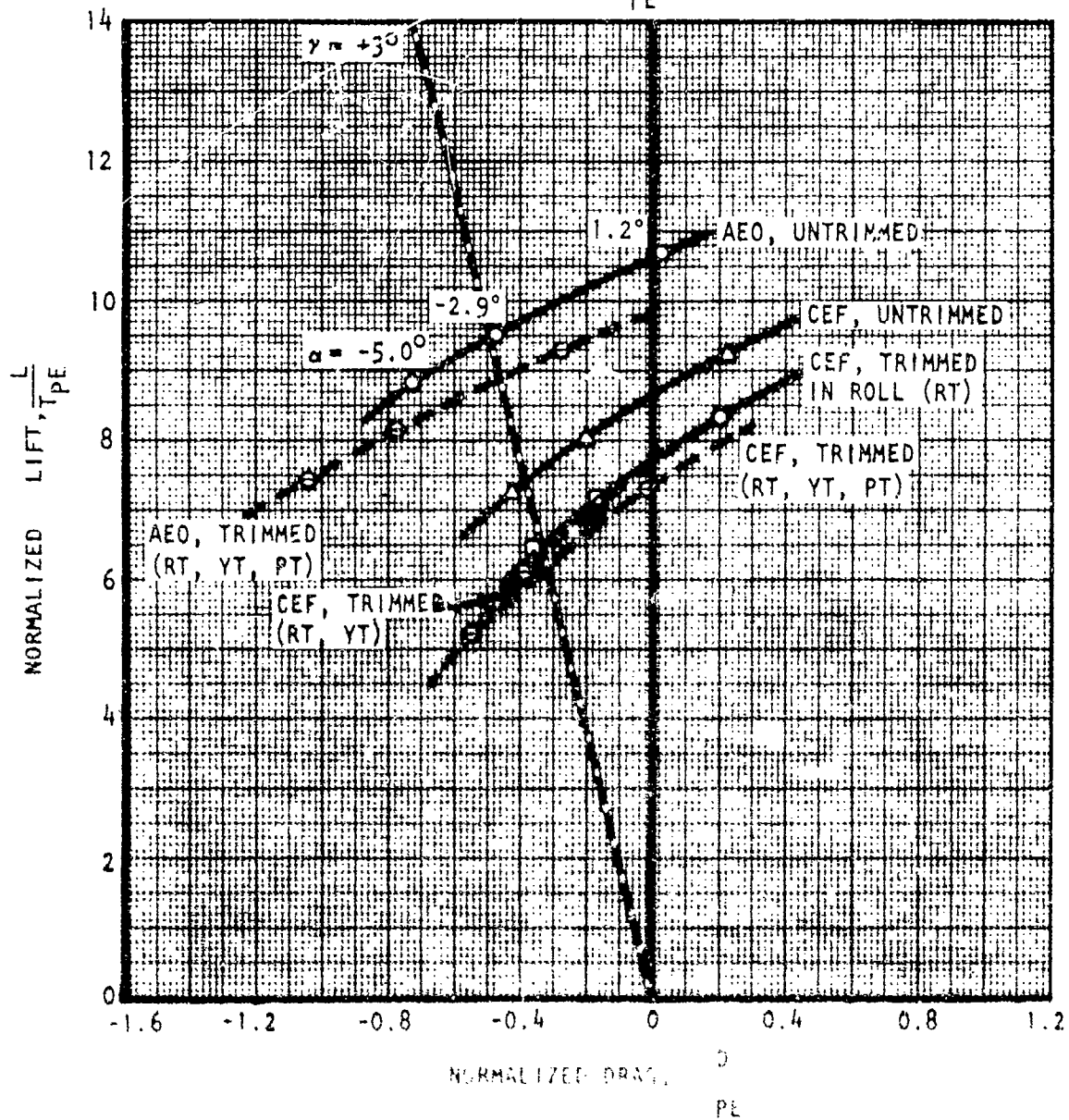
$\boxed{C_{\mu_{PE}} = 0.50}$ $\dfrac{q}{T_{PE}/S} = 2.00$

Figure 10. Full-Span, Double Slotted Flaps

17

$$\delta_F = 2.5°/20°/25°$$

NO AILERON BLC

$$\boxed{C_{\mu_{PE}} = 0.825} \qquad \frac{q}{T_{PE}/S} = 1.21$$
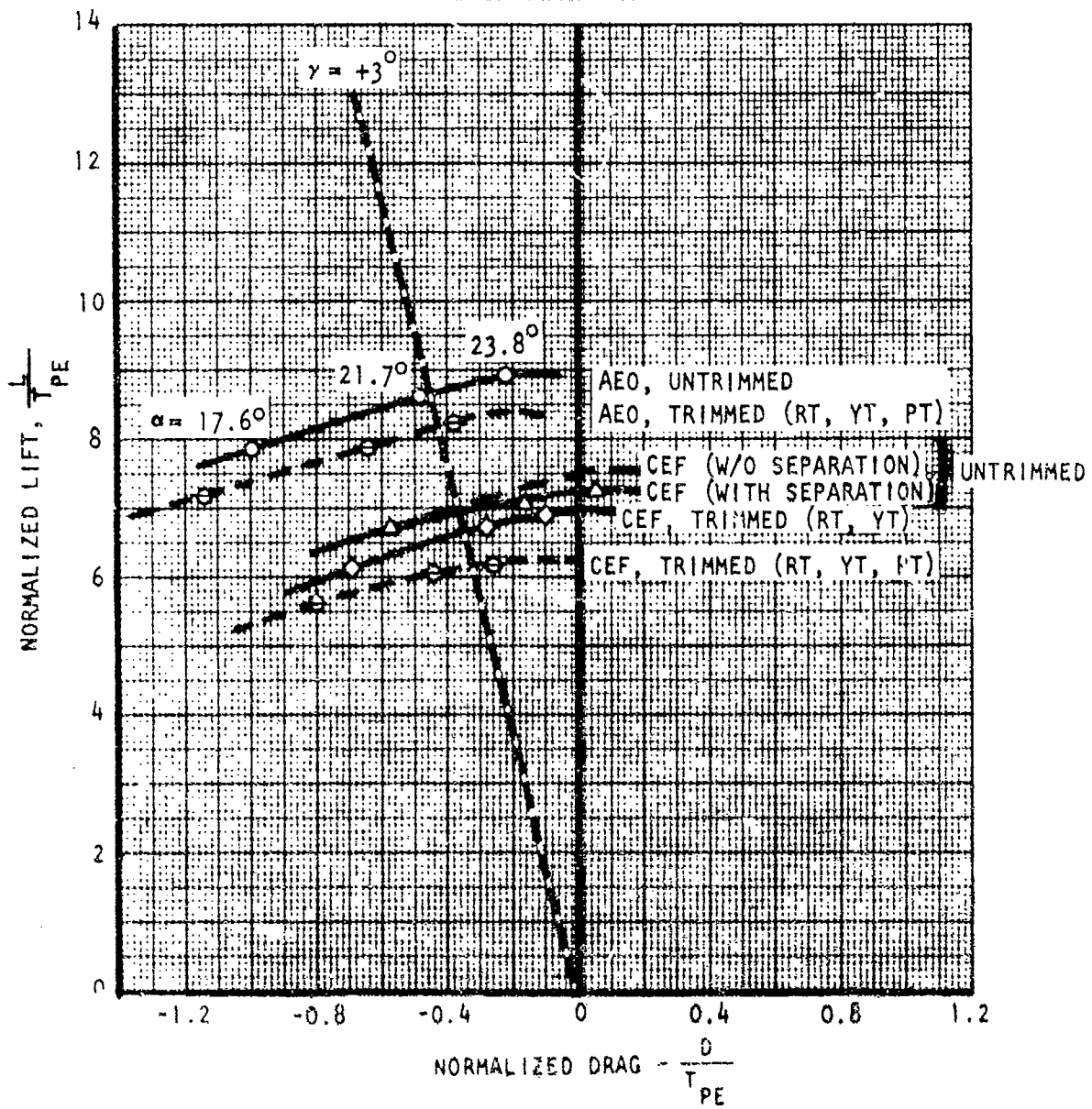
Figure 11. Full-Span Triple-Slotted Flaps
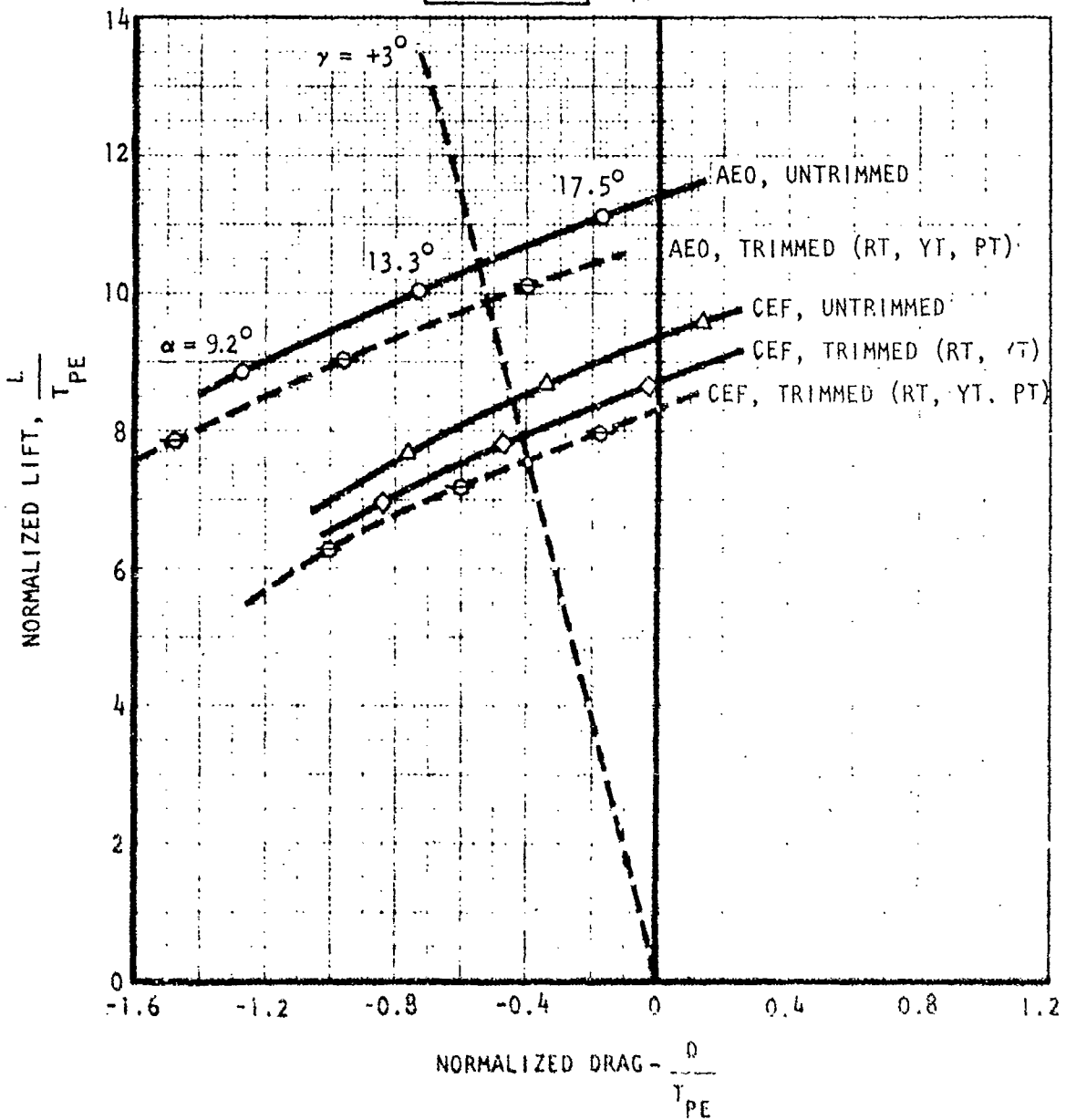
Figure 12. Full-Span, Triple-Slotted Flaps

$\delta_F = 2.5°/20°/45°$

NO AILERON BLC

$\boxed{C_{\mu_{PE}} = 0.825}$ $\dfrac{q}{T_{PE}/S} = 1.21$
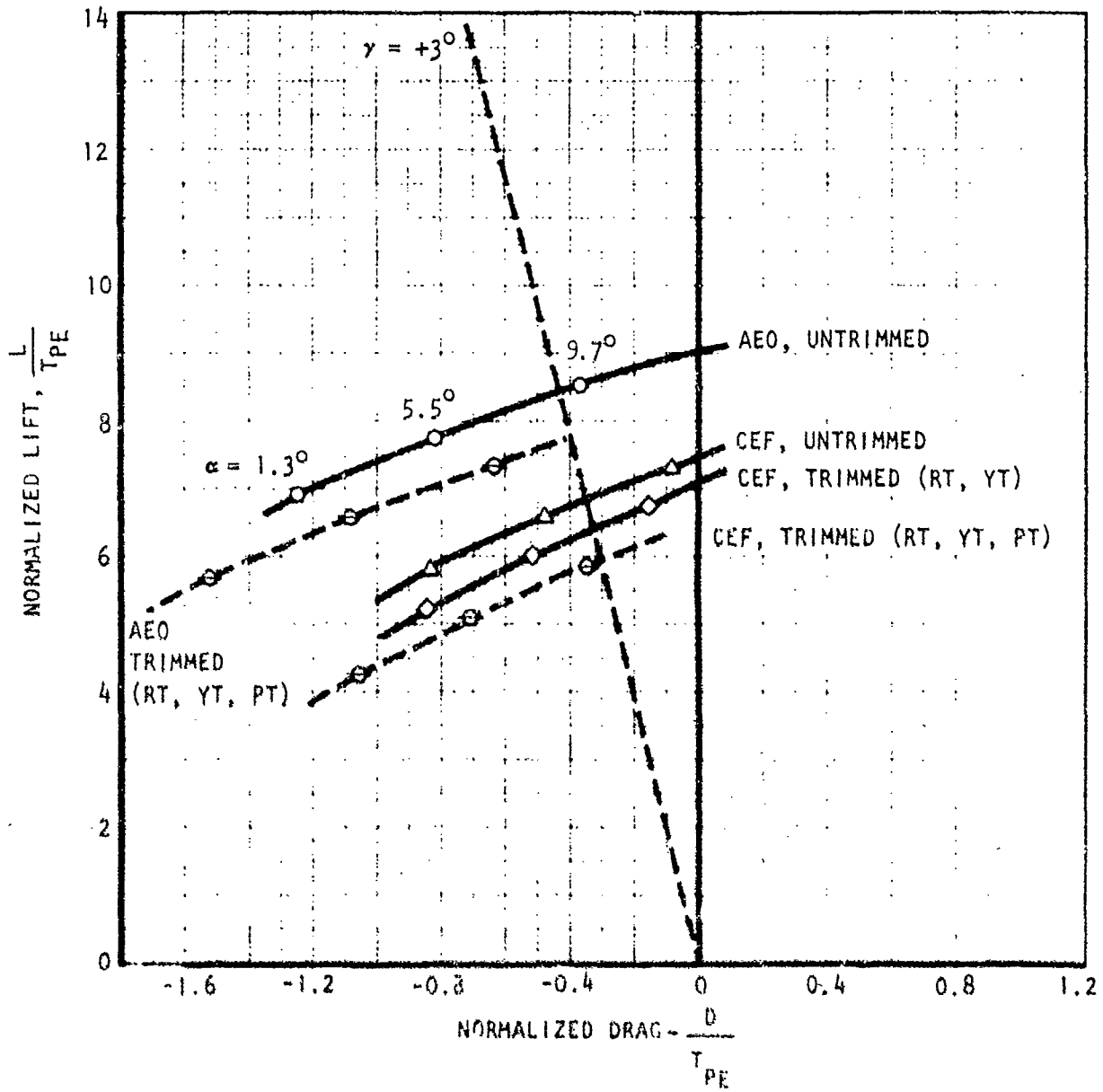
Figure 13. Full-Span, Triple-Slotted Flaps
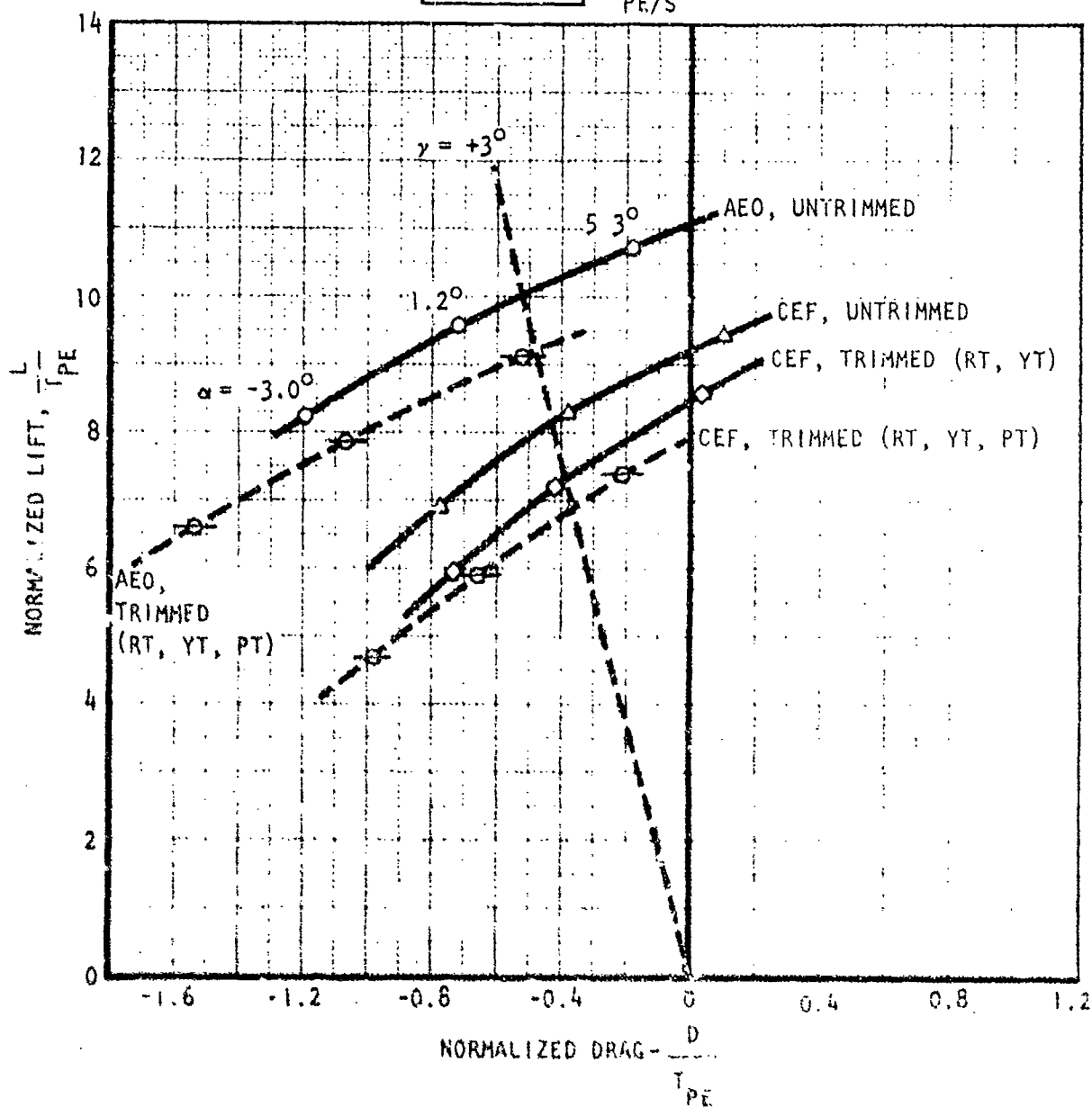
Figure 14. Full-Span, Triple-Slotted Flaps

21

$$\delta_F = 25°/30°$$

$$\boxed{C_{\mu PE} = 0.825} \qquad \frac{q}{T_{PE}/S} = 1.21$$
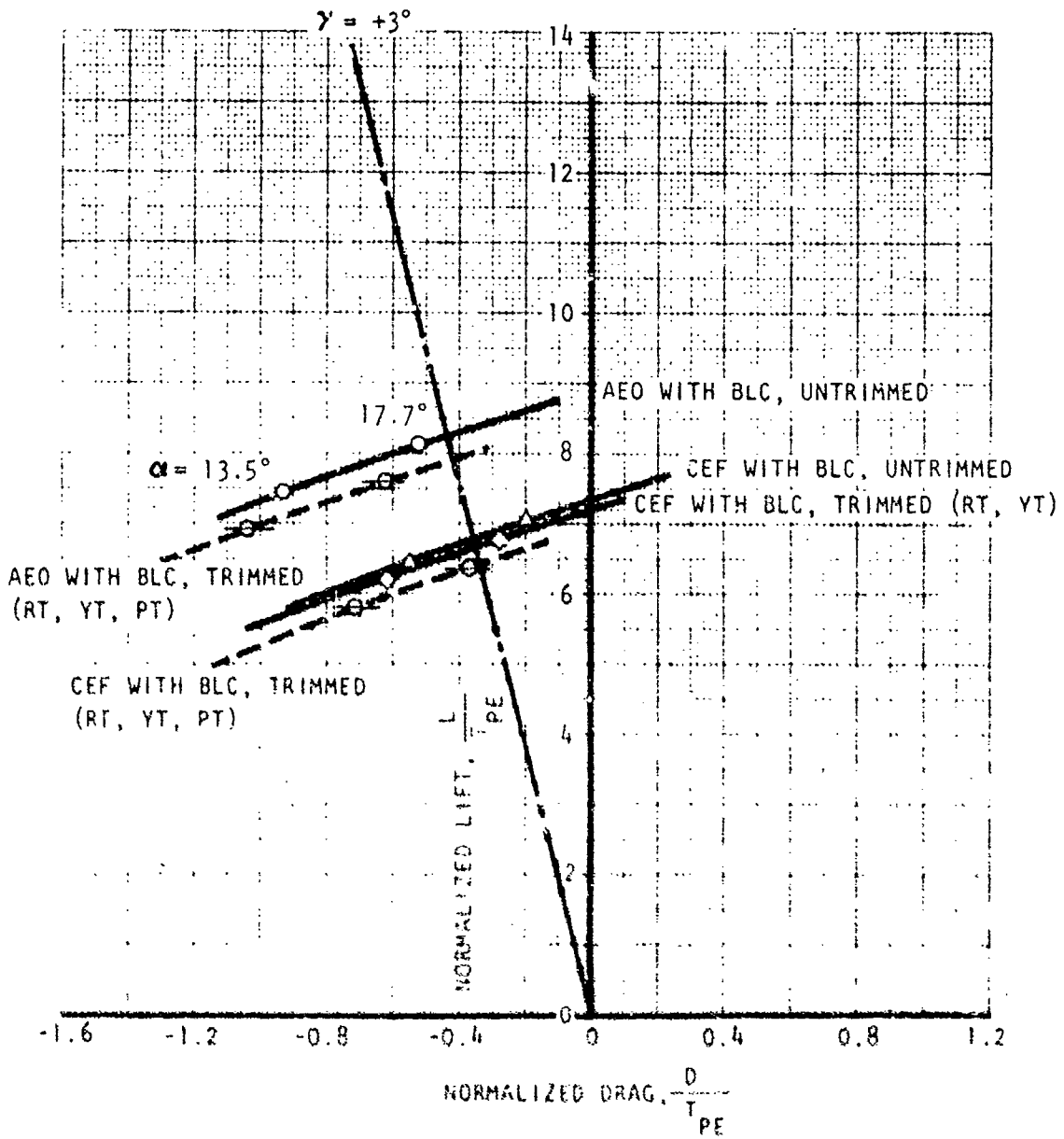
Figure 15. Partial Span, Double Slotted Flaps With BLC at Ailerons

38

$\delta_F = 25°/30°$

$C_{\mu_{PE}} = 0.50$ $\dfrac{q}{T_{PE}/S} = 2.00$

$\gamma = +3°$

$13.5°$

AEO WITH BLC, UNTRIMMED

$9.3°$

CEF WITH BLC, UNTRIMMED
CEF WITH BLC, TRIMMED
(RT, YT)

$\alpha = 5.1°$

AEO WITH BLC,
TRIMMED
(RT, YT, PT)

CEF WITH BLC,
TRIMMED
(RT, YT, PT)

NORMALIZED LIFT, $\dfrac{L}{T_{PE}}$

-1.6   -1.2   -0.8   -0.4   0   0.4   0.8   1.2

NORMALIZED DRAG,
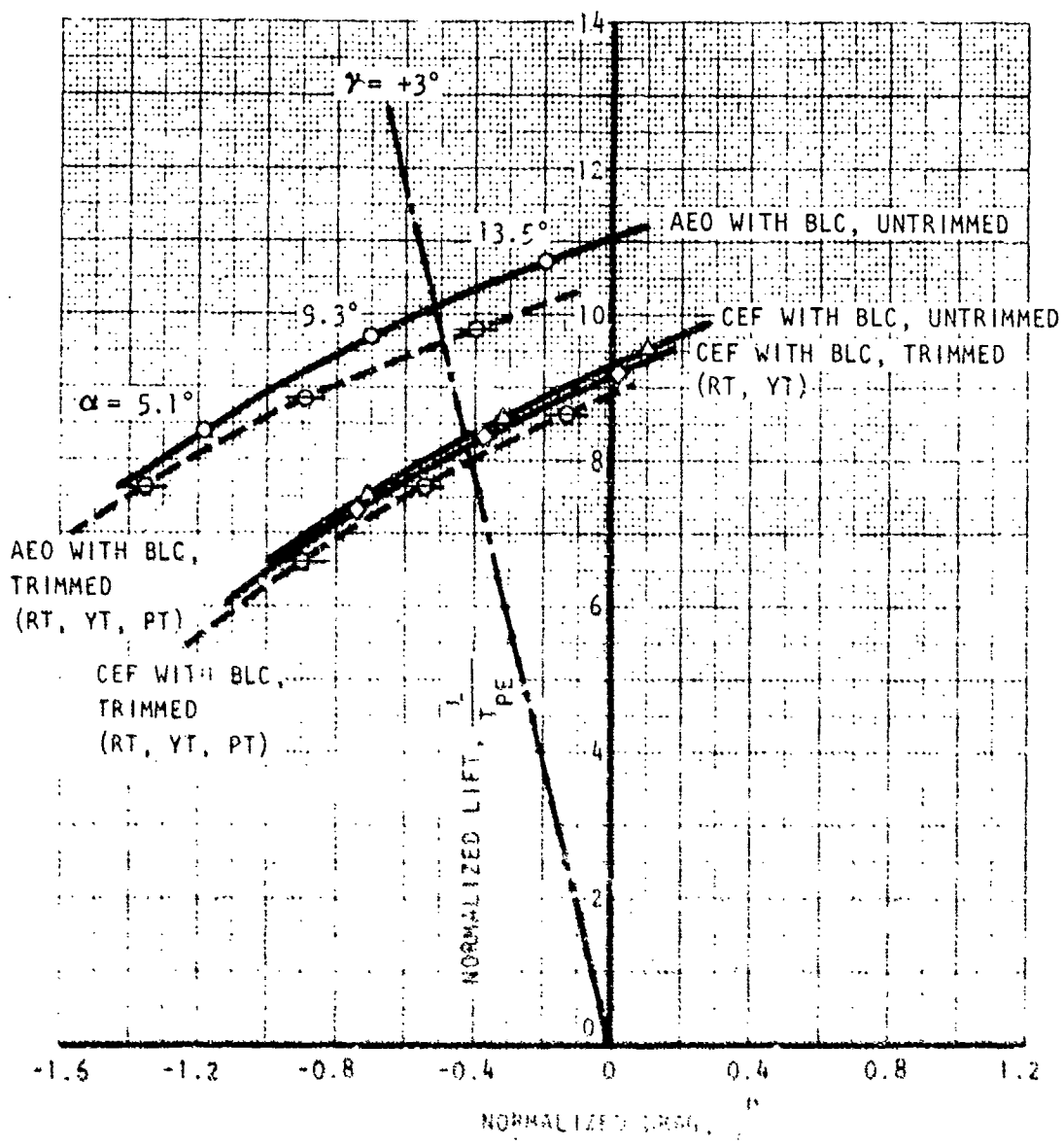
Figure 16. Partial-Span, Double-Slotted Flaps With BLC at Ailerons

$\delta_F = 2.5°/20°/25°$

$$C_{\mu PE} = 0.8\ 25 \qquad \frac{q}{T_{PE}/S} = 1.21$$
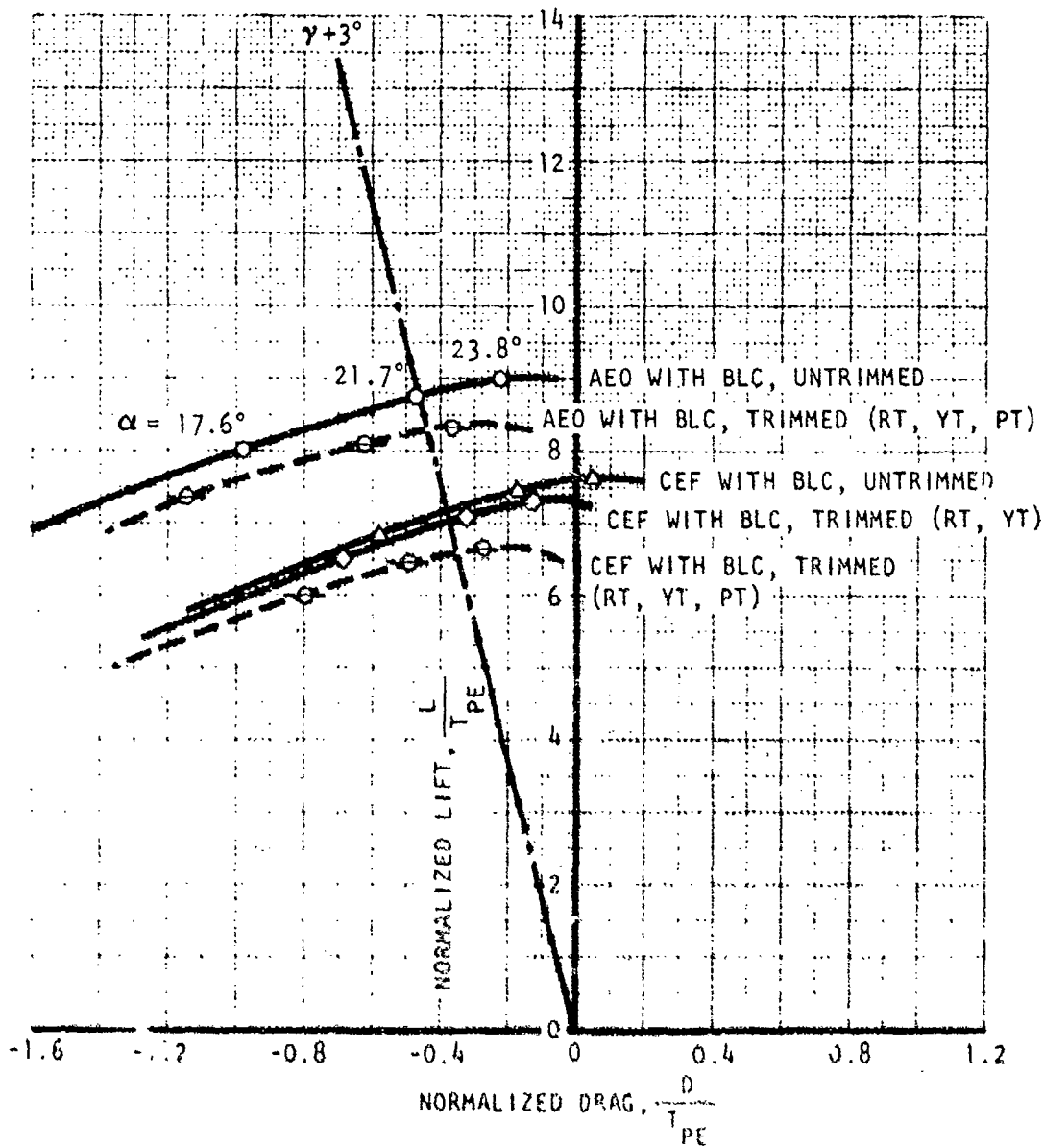
Figure 17. Partial-Span, Triple-Slotted Flaps With BLC at Ailerons

24

$$\delta_F = 2.5°/20°/25°$$

$$C_{\mu_{PE}} = 0.50 \qquad \frac{q}{T_{PE}/S} = 2.00$$
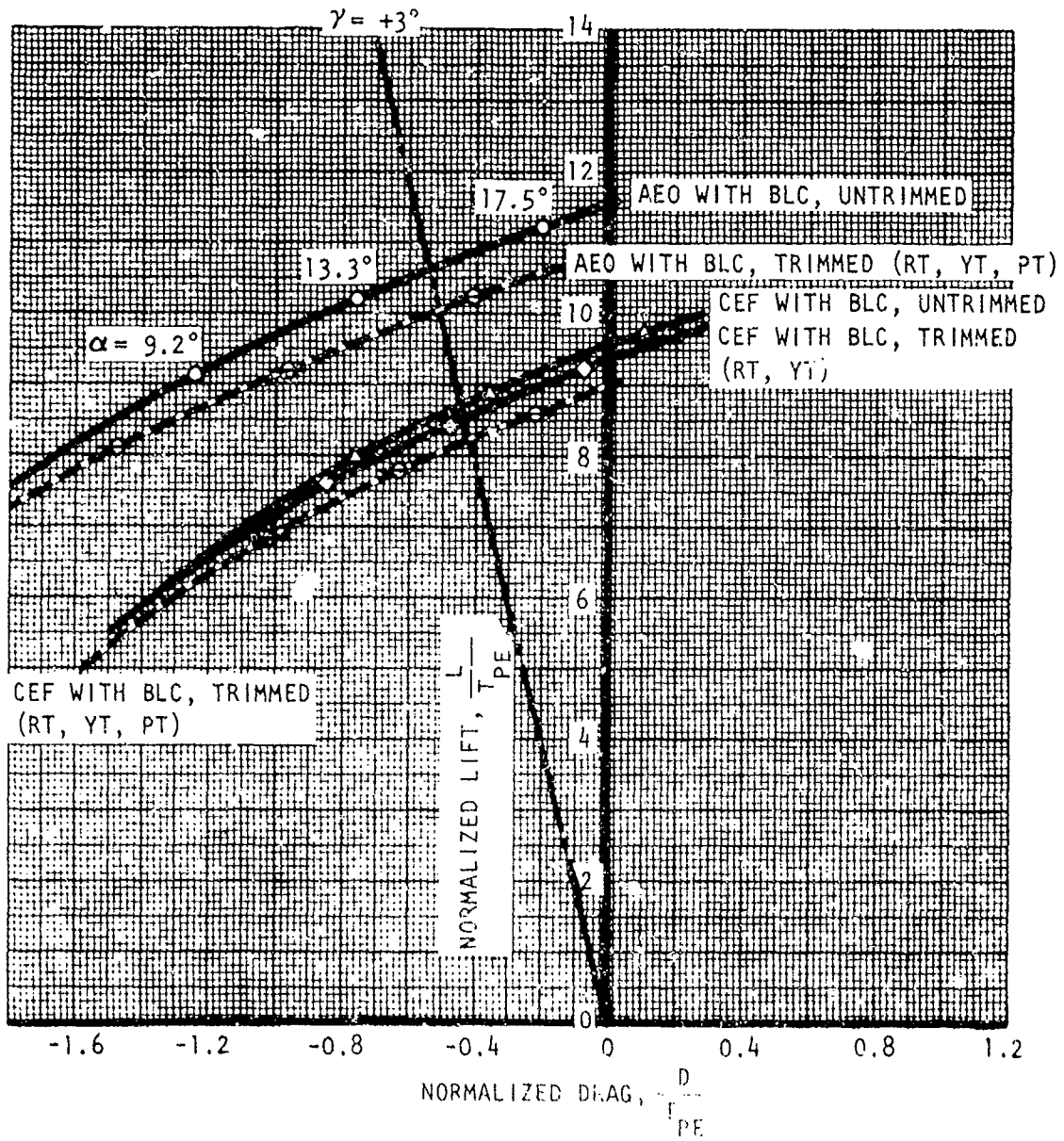
Figure 18. Partial - Span, Triple-Slotted Flaps With BLC at Ailerons

25

The figures pertain to the following geometries and speed parameters:

Figure	Type of Flap	Aileron BLC	Flap Deflection	$\frac{q}{T_{PE}/S}$
7	Full Span Double Slotted	No	25°/30°	1.21
8	"	"	"	2.00
9	"	"	25°/50°	1.21
10	"	"	"	2.00
11	Full Span Triple Slotted	No	25°/20°/25°	1.21
12	"	"	"	2.00
13	"	"	25/20/45°	1.21
14	"	"	"	2.00
15	Inbd Double Slotted,	Yes	25°/30°	1.21
16	Tip Single Slotted	"	"	2.00
17	Inbd Triple Slotted,	"	25°/20°/25°	1.21
18	Tip Single Slotted	"	"	2.00

Each plot shows at the upper line the untrimmed (tail-off) wind tunnel data with all engines operating (open symbols). The first lower line with open symbols represents untrimmed data with the outboard engine inoperative. The two lines with solid symbols represent conditions trimmed in roll (roll trim, RT), yaw (YT), and pitch (PT) for the case that all engines are operating and the case of engine failure. It is primarily the lowest line with solid symbols that is of interest for the present comparison, being the engine failure case.

The determination of the various changes in lift and drag due to trimming is discussed in later subsections.

Climb conditions, at which $\gamma = +3°$ is satisfied, are indicated in these figures, and intersections are plotted versus flap angle in Figures 19 and 20.

These plots generally show a maximum value of L/T_{PE} at a low flap angle. This maximum is of interest because it represents the maximum lifting capability of the aircraft under the climb condition with $\gamma = +3°$. However, at low flap angles not enough flight safety margin in terms of speed or maneuver capability may exist. For this reason also the maximum trimmed lift with all engines operating and with one engine inoperative needs to be determined so that speed and maneuver margins can be compared. Conditions at which these margins exist are determined as follows.

$$\boxed{\gamma = +3°}$$

TRIMMED CONDITION

$$\delta_F = 25°/(XX)$$

FLAGGED SYMBOL: PARTIAL SPAN FLAP
WITH BLC AT AILERONS

UNFLAGGED   FULL SPAN FLAP W/O
SYMBOL: BLC AT AILERONS

Figure 19. Double-Slotted Flaps With and Without BLC At Ailerons

27

Figure 20. Triple-Slotted Flaps With and Without BLC at Ailerons

28

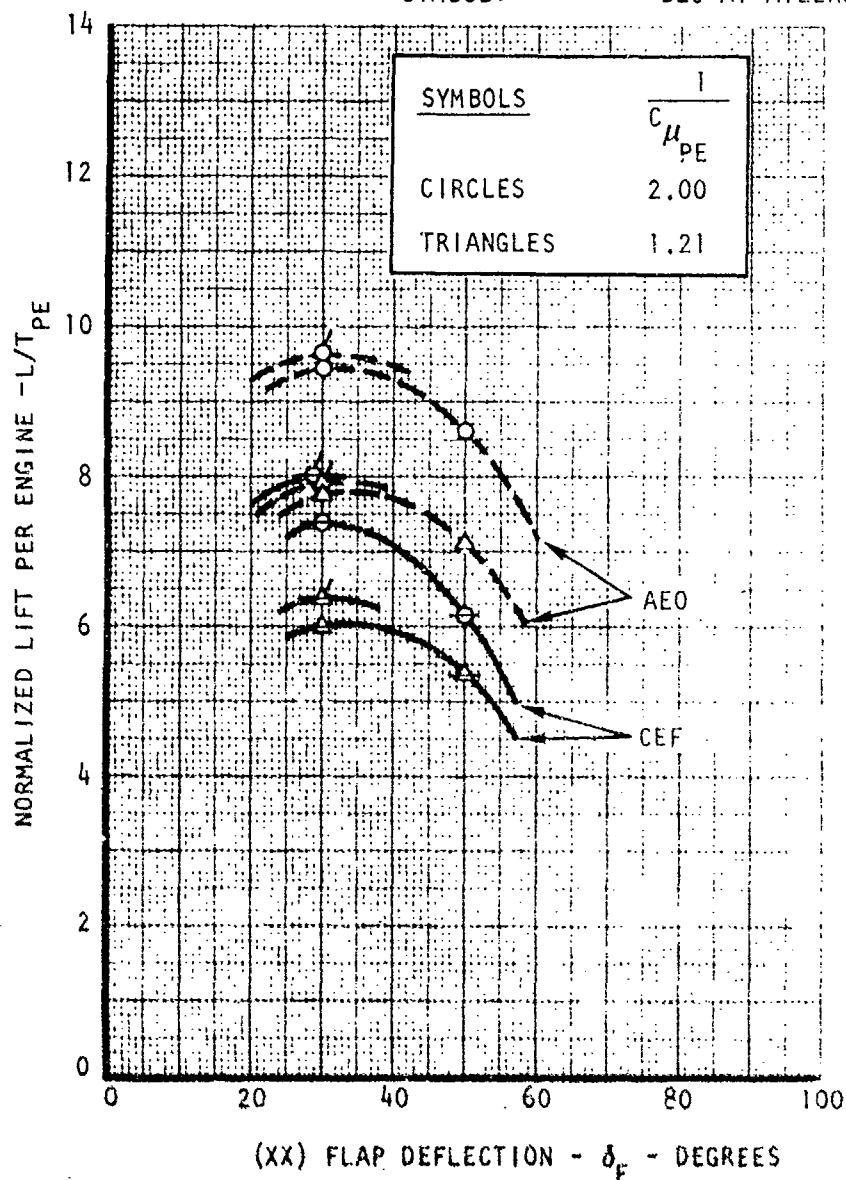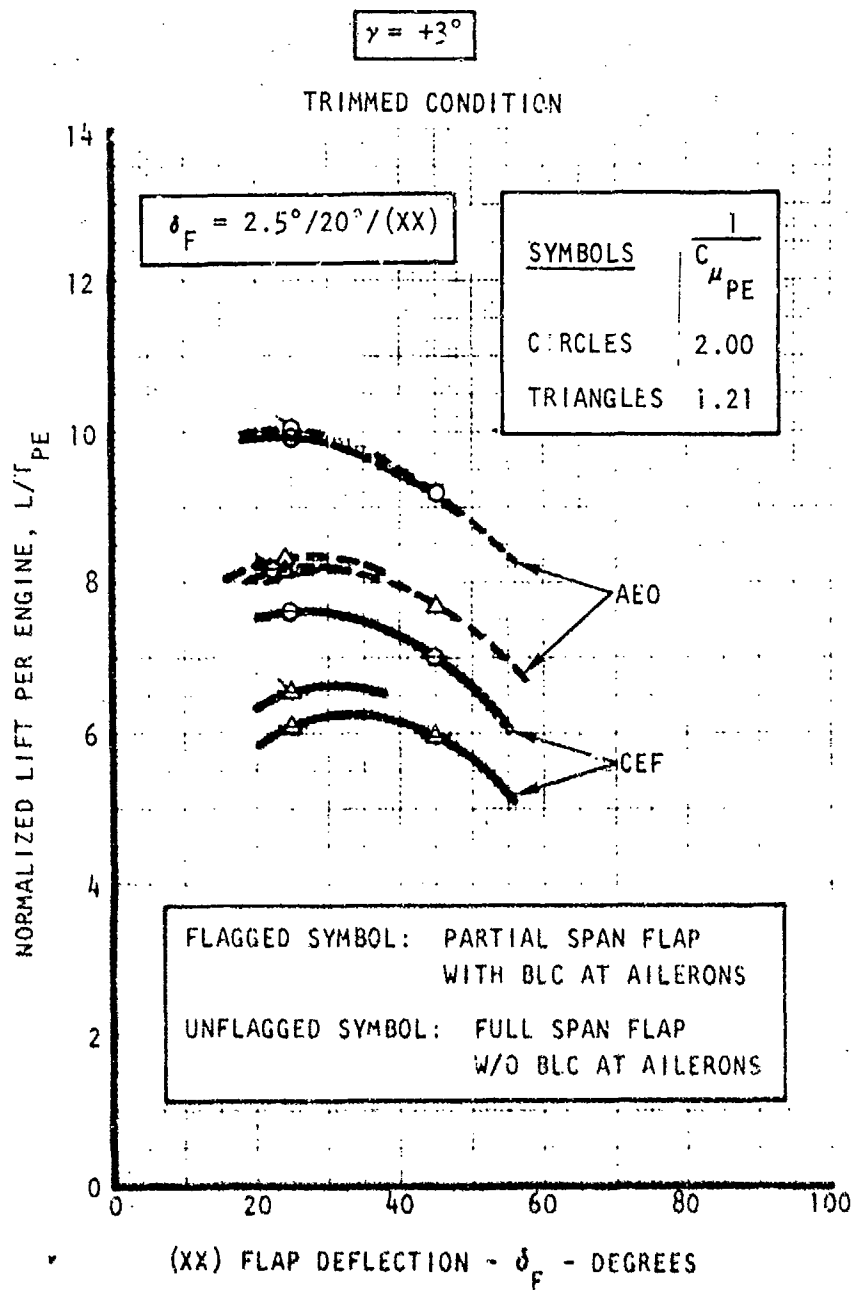The maximum lifts are shown in Figure 21 for low flap angles, and in Figure 22 for higher flap angles. The maximum lift with all engines operating is defined as the lift at $\alpha = 18°$. This angle is equal to the stall angle with one engine inoperative to avoid large uncontrollable rolling moments in case an engine fails. The conditions pertain to flight out of ground effect. Maneuver margins and speed margins can now be applied as illustrated in Figures 23 and 24. Figures 25 and 26 show conditions where a speed margin of 10 percent exists with respect to the CEF condition. Cross plots at given values of $C_{\mu PE}$ can now be made as a function of flap angle for conditions with this speed margin and also with a maneuver margin n = 1.3. This is shown in Figures 27 through 30. Results can directly be compared in these figures with the conditions for which $\gamma = 3°$ and which are repeated from previous plots.

It is seen that, generally, the safety margins prevent the use of the maximum L/T_{PE} values for $\gamma = 3°$. A higher flap angle needs to be taken that lowers L/T_{PE} slightly. Lift values that meet these safety margins as well as $\gamma = 3°$ are presented in Figure 31.

This figure is now used to compare the lifting capability and speed capability for given engine thrusts with one engine inoperative.

Using W/S = 80 lbs/ft^2 and V = 80 KEAS as sample values, the following is obtained according to the method schematically shown in Figure 32:

$$\frac{L/T_{PE}}{(1/C_{\mu PE})} = \frac{L/T_{PE}}{\frac{q}{T_{PE}/S}} = \frac{W/T_{PE}}{\frac{q}{T_{PE}/S}} = \frac{W/S}{q} = \frac{80}{21.7} = C_L = 3.68$$

Configuration	W/T$_{PE}$	T/W
Full Span Double Slotted Flaps	7.28	.550
Inboard Double Slotted Flaps + Outboard Single Slotted Flaps with BLC	8.48	.472
Full Span Triple Slotted Flaps	7.75	.516
Inboard Triple Slotted Flaps + Outboard Single Slotted Flaps With BLC	8.85	.452
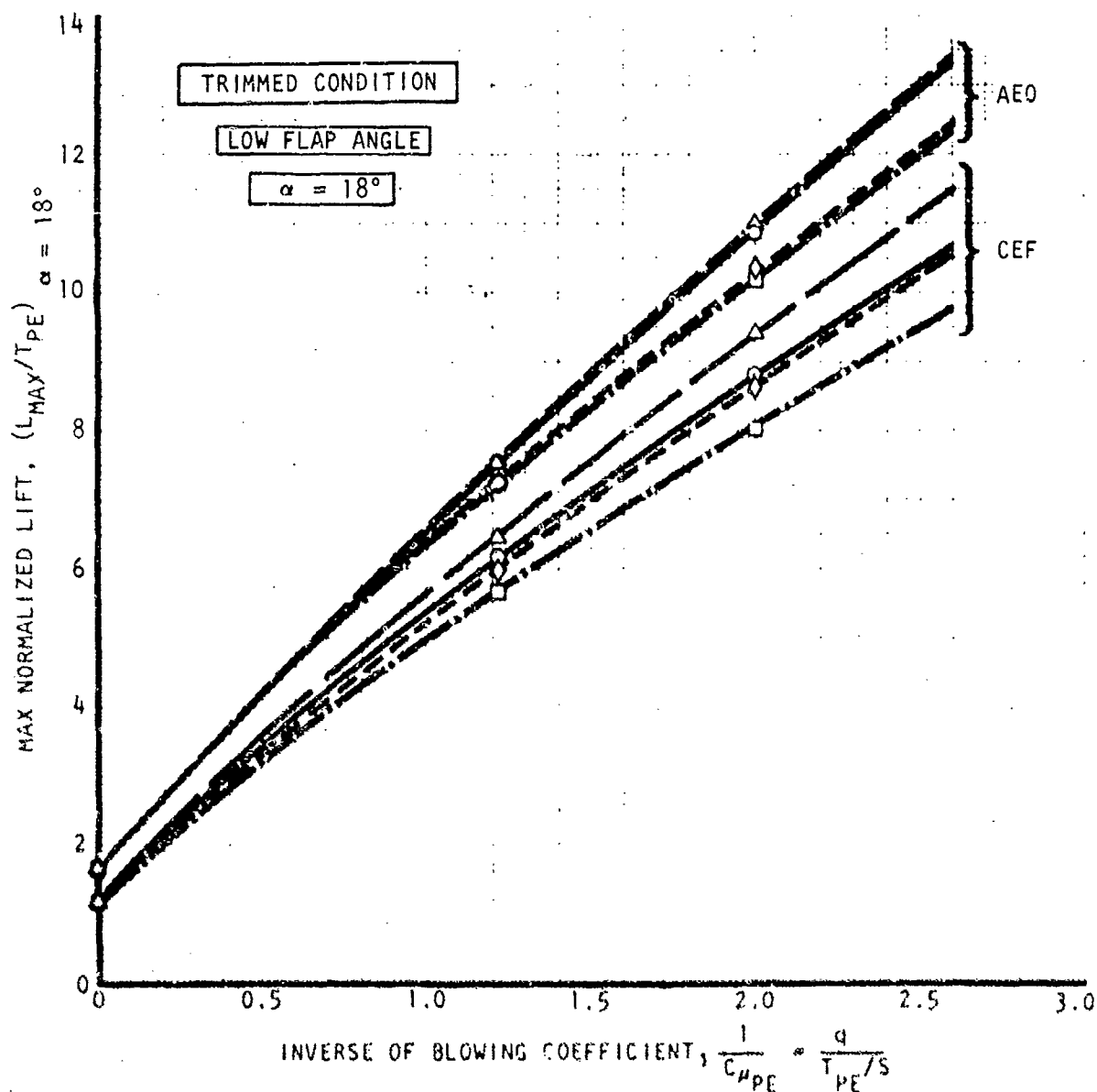
Figure 21. Maximum Lift, Double and Triple-Slotted Flaps With and Without BLC at Ailerons

TRIMMED CONDITION

HIGH FLAP ANGLE
$\alpha = 18°$
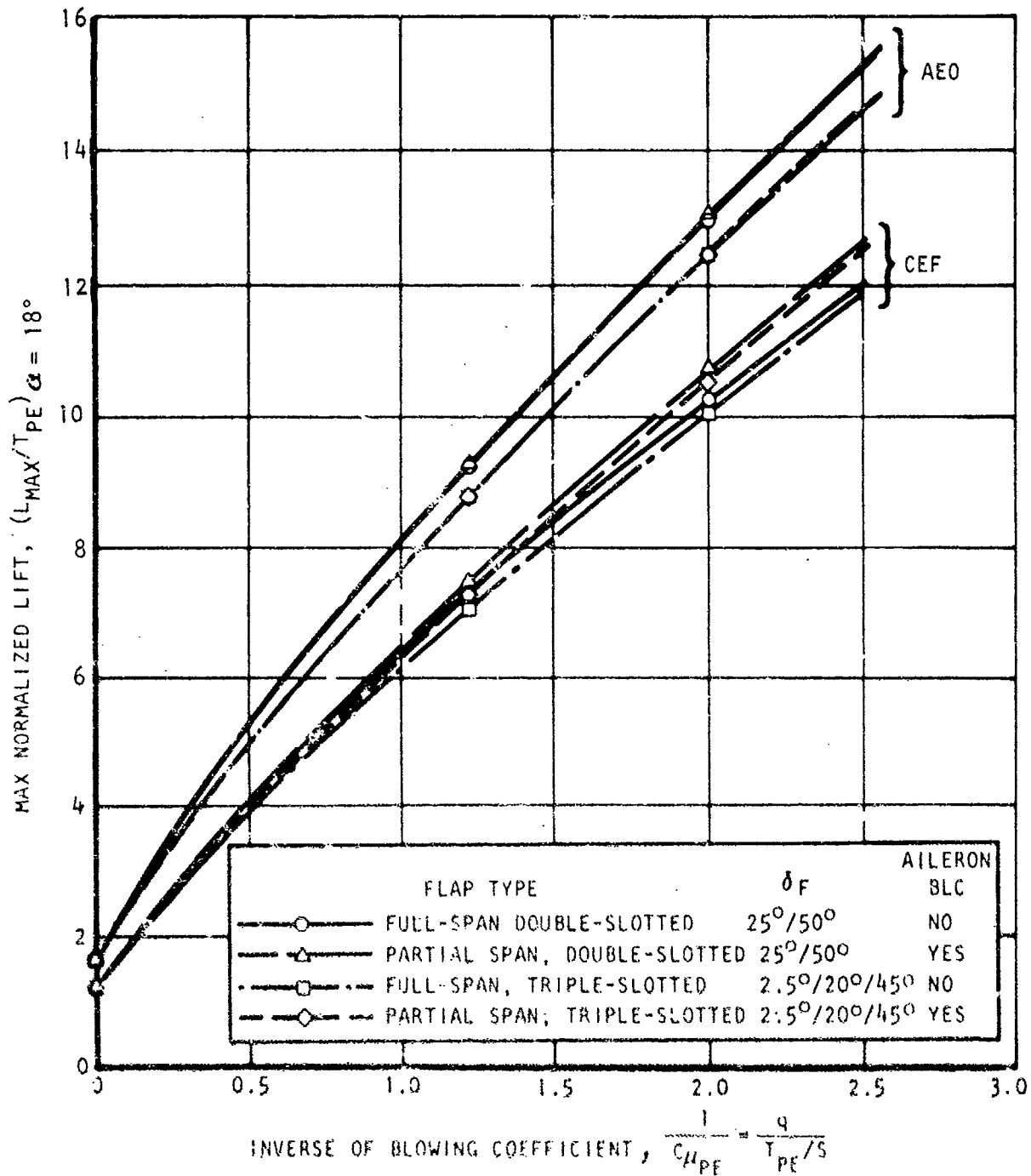
Figure 22. Maximum Lift, Double - and Triple-Slotted Flap Comparison
With and Without BLC at Ailerons

31
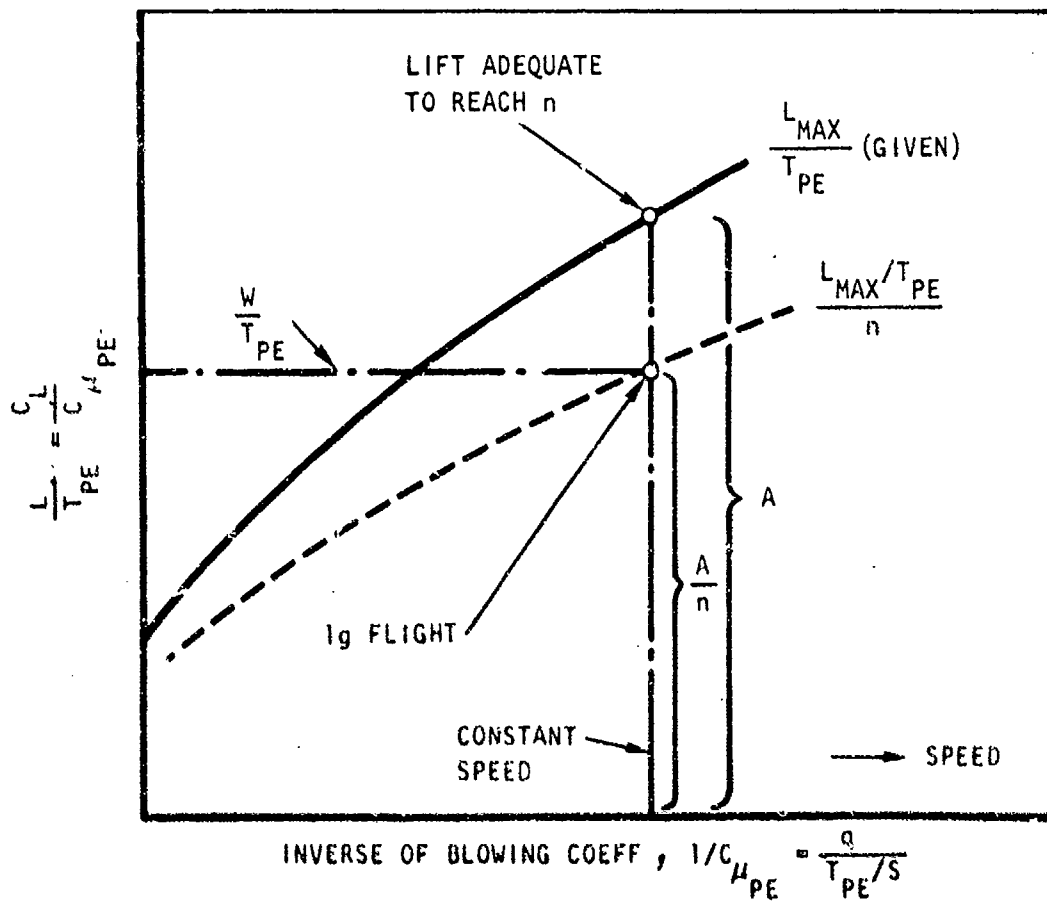
Figure 23. Determination of Flight Condition at Which a Given Maneuver Margin Exists

Figure 24. Determination of Flight Condition at Which a 10-Percent Speed Margin Exists

LIFT AT 10% SPEED MARGIN

TRIMMED CONDITION
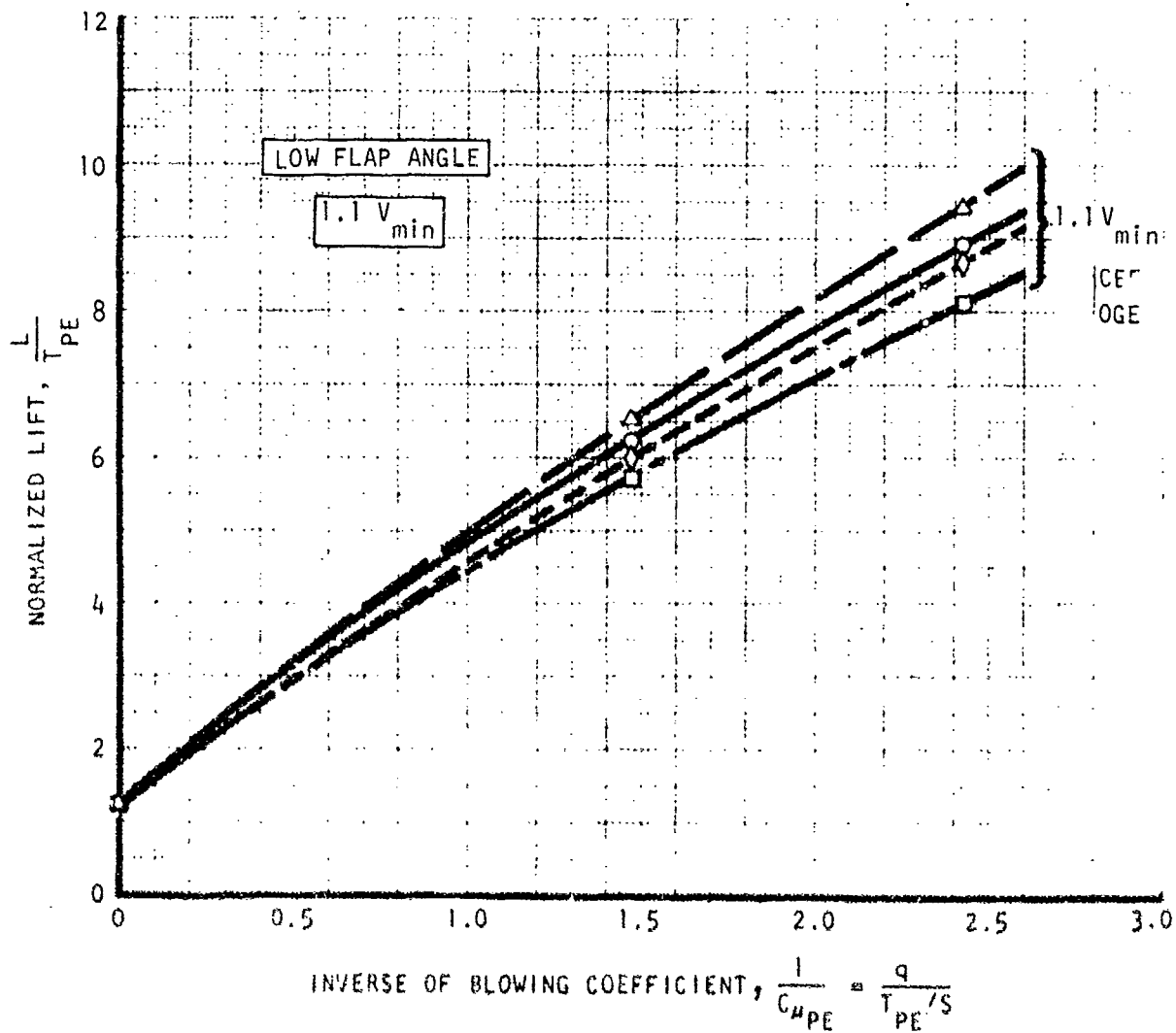
Figure 25. Lift at 10% Speed Margin, Double and Triple-Slotted Flap Comparison With and Without BLC at Ailerons

TRIMMED CONDITION

HIGH FLAP ANGLE

$1.1\ V_{min}$

FLAP TYPE	δ_F	AILERON BLC
FULL-SPAN, DOUBLE-SLOTTED	25°/50°	NO
PARTIAL-SPAN, DOUBLE-SLOTTED	25°/50°	YES
FULL-SPAN, TRIPLE-SLOTTED	2.5°/20°/45°	NO
PARTIAL-SPAN, TRIPLE-SLOTTED	2.5°/20°/45°	YES
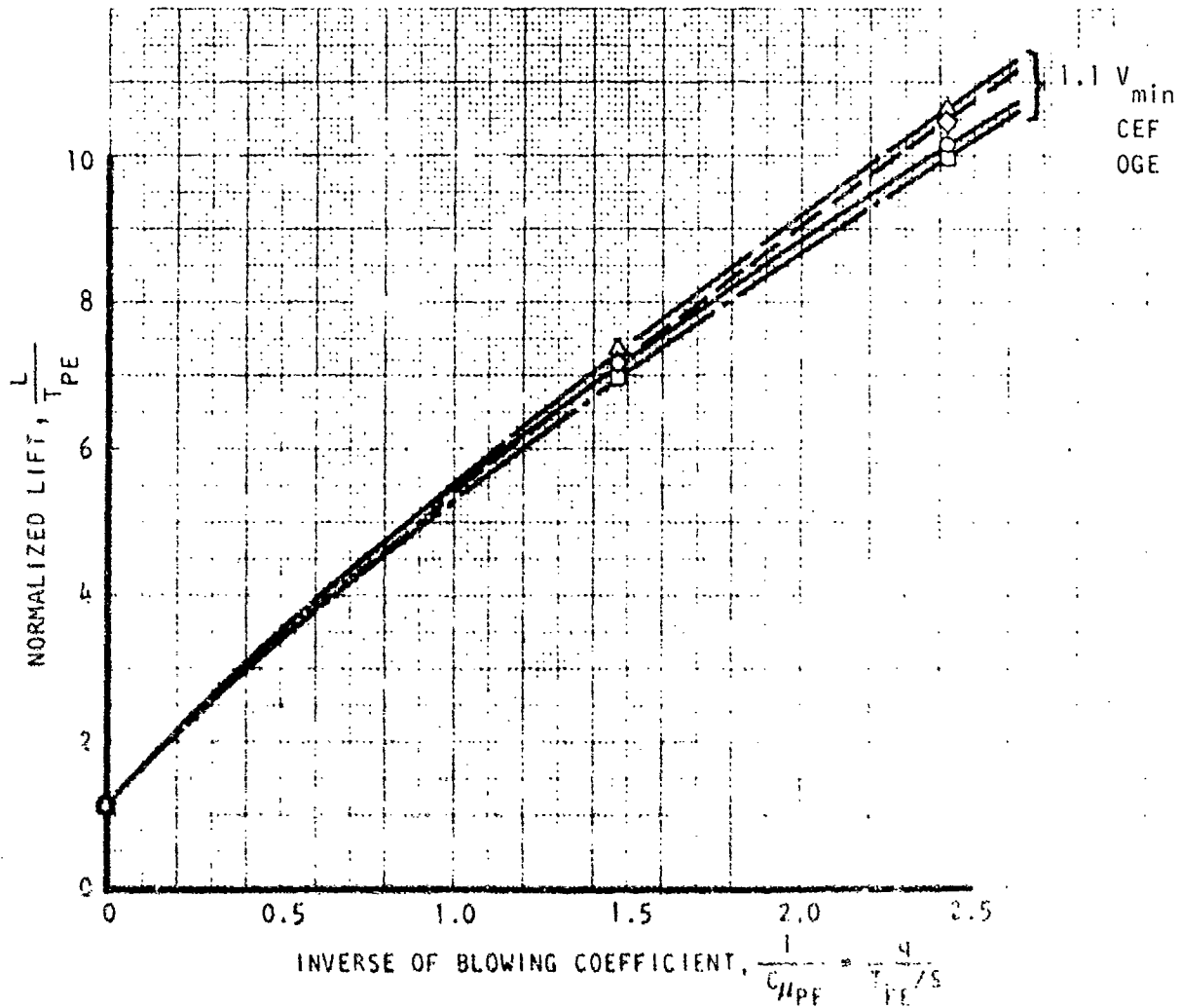
Figure 26. Lift at 10% Speed Margin, Double and Triple-Slotted Flaps With and Without BLC at Ailerons

35
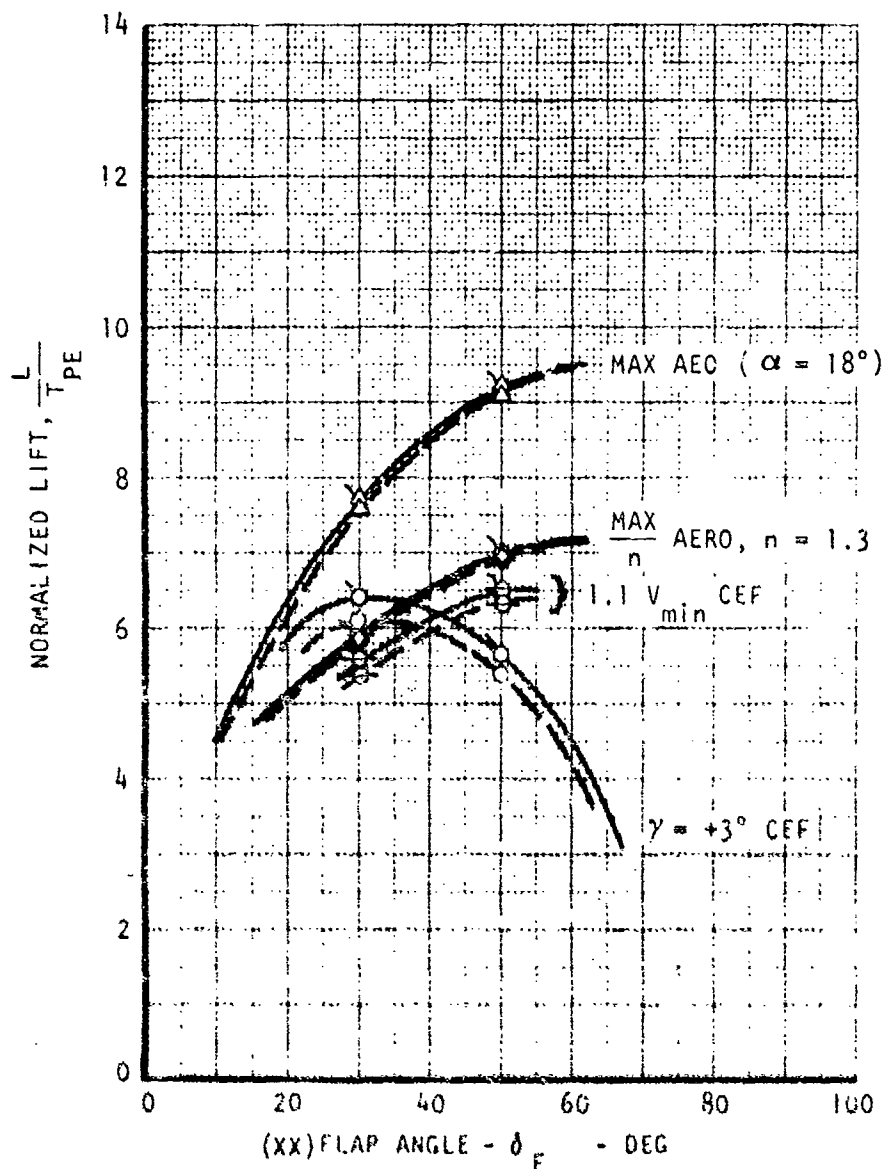
Figure 27. Determination of Flap Setting for Takeoff - Double-Slotted Flaps With and Without BLC

$\delta_F = 25°/(XX)$

TRIMMED CONDITION

$$\frac{1}{C_{\mu_{PE}}} = \frac{q}{T_{PE}/S} = 2.00$$

	AIL
	BLC
⊸⊙⊸	YES
--⊙--	NO
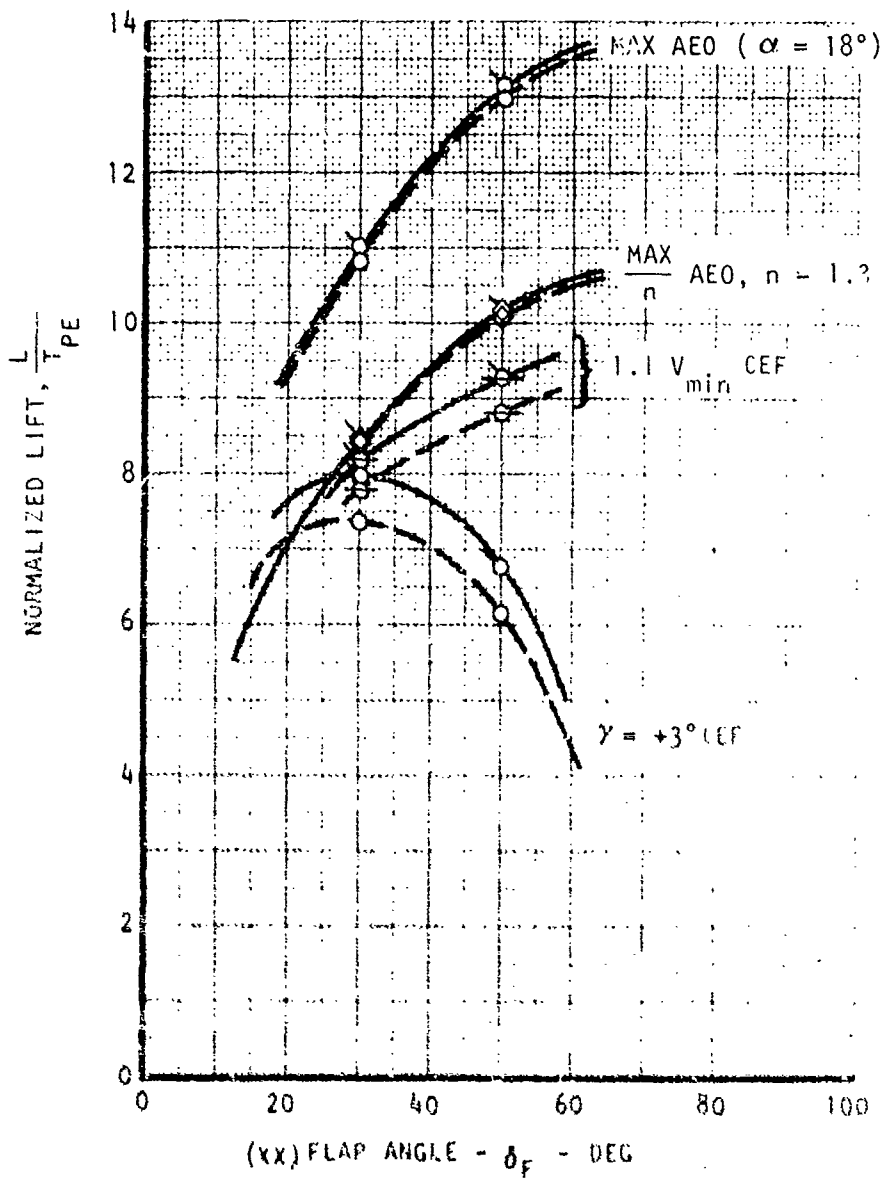
Figure 28. Determination of Flap Setting for Takeoff - Double Slotted Flaps With and Without BLC

$\delta_F = 2.5°/20°/(XX)$
TRIMMED CONDITION

$$\frac{1}{C_{\mu_{PE}}} = \frac{q}{T_{PE}/S} = 1.21$$

AIL
BLC
YES
NO

14

12

10

MAX AEO ($\alpha = 18°$)

NORMALIZED LIFT, $\frac{L}{T_{PE}}$

8

$\frac{MAX}{n}$ AEO, n = 1.3

1.1 V_{min} CEF

6

$\gamma = +3°$ CEF

4

2

0

0   20   40   60   80   100

(XX) FLAP ANGLE - δ_F - DEG
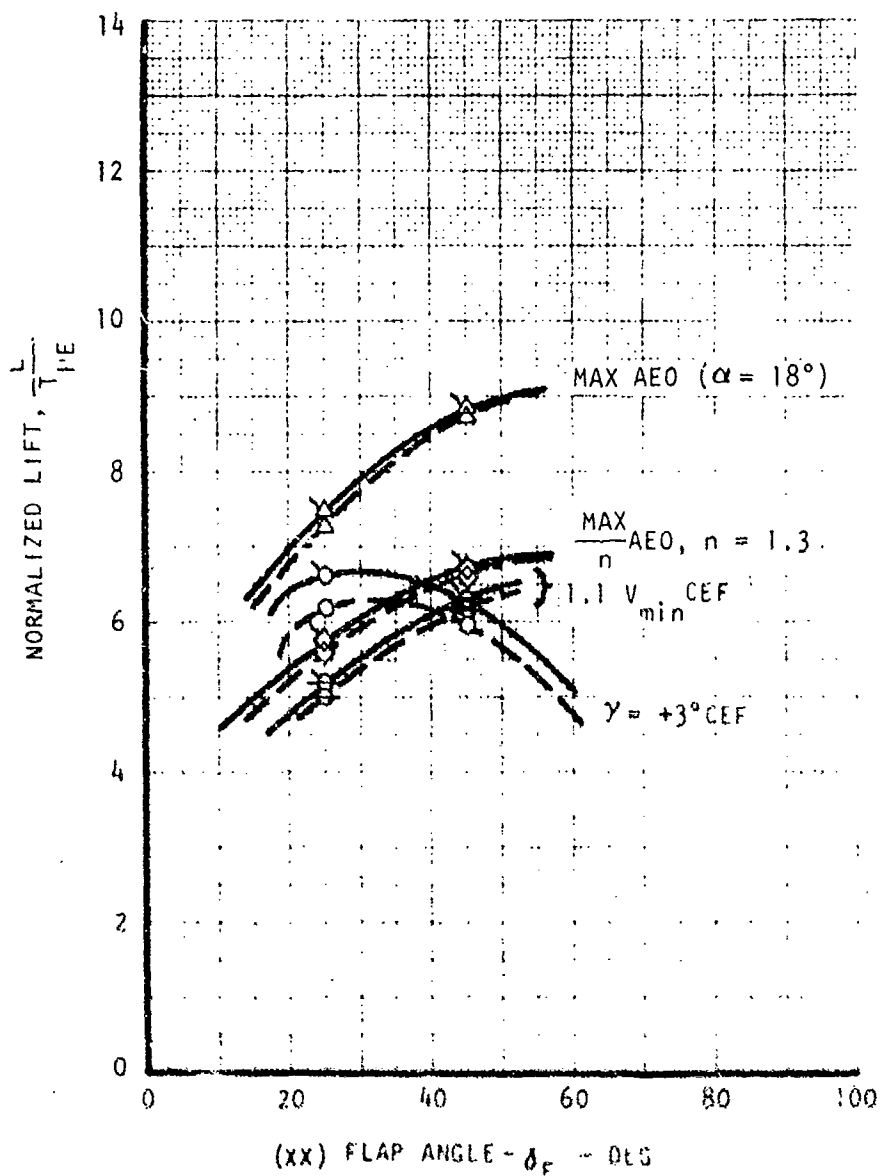
Figure 29. Determination of Flap Setting for Takeoff - Triple-Slotted Flaps
With and Without BLC

38

$\delta_F = 2.5°/20°/(XX)$
TRIMMED CONDITION

$$\frac{1}{c_{\mu_{PE}}} = \frac{q}{T_{PE}/S} = 2.00$$

Figure 30. Determination of Flap Setting for Takeoff-Triple-Slotted Flaps With and Without BLC

	FLAP	AILERON BLC
──────○	FULL-SPAN, DOUBLE SLOTTED	NO
── ──△	PARTIAL-SPAN, DOUBLE SLOTTED	YES
──·──□	FULL-SPAN, TRIPLE SLOTTED	NO
────◇	PARTIAL-SPAN, TRIPLE SLOTTED	YES

CRITICAL ENGINE INOPERATIVE
TRIMMED CONDITION

NORMALIZED LIFT, $\frac{L}{T_{PE}}$

$\gamma = +3°$
$V = 1.1 V_{min}$ CEF, OGE
$n \gtrsim 1.3$ FOR AEO, OGE

INVERSE OF BLOWING COEFF, $\dfrac{1}{C_{\mu_{PE}}} = \dfrac{q}{T_{PE}/S}$
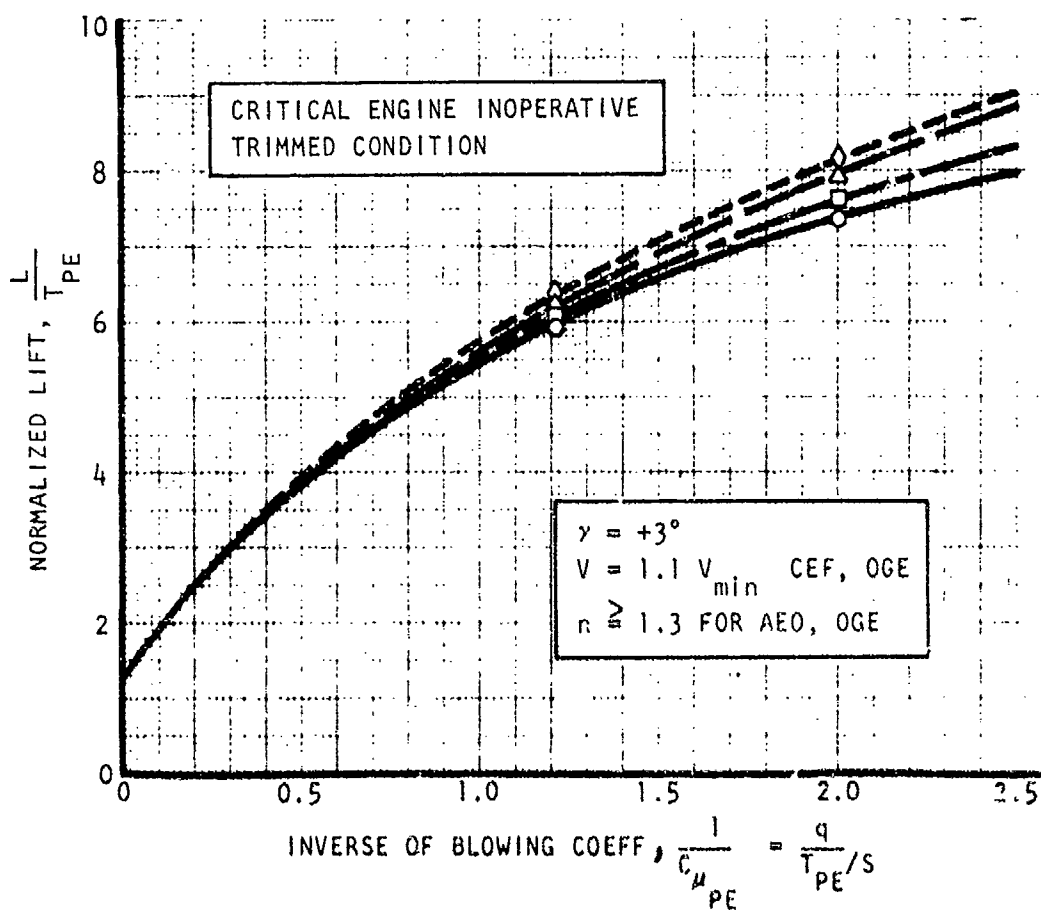
Figure 31. Lifting Capability of Double and Triple-Slotted Flaps With
and Without BLC at Ailerons

40
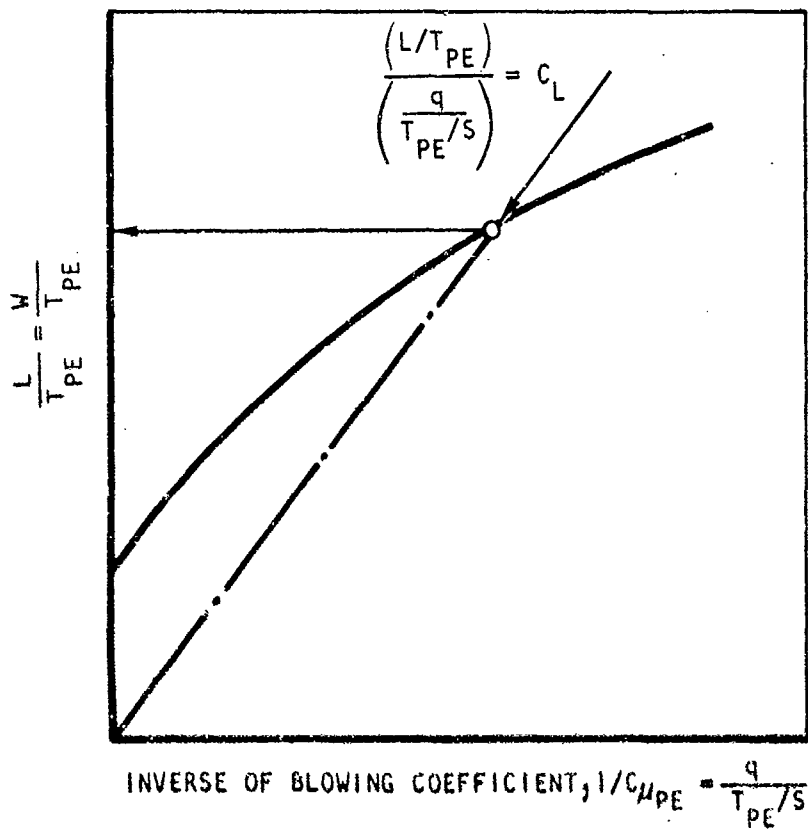
Figure 32. Determination of Thrust - to - Weight Ratio When the Lift Coefficient is Given

It is seen that an engine exhaust thrust saving of about 5 percent can be realized in going from a double slotted to a triple slotted flap (i.e., .516/.550 and .452/.472), and about a 13 percent saving in going from full span flaps without BLC to partial span flaps and tip surfaces with a total BLC of $C_{\mu_{AIL}} = .065$ (i.e., .472/.550 and .452/.516).

If, on the other hand, the aircraft weight and the engine static exhaust thrust are held constant, the capabilities of the various geometries can be expressed in a difference in speed. If $W/S = 80$ and $T/W = .55$, the following equations are used to obtain speeds at which it is possible to climb with $\gamma = +3°$ with one engine inoperative

$$\frac{L}{T_{PE}} = \frac{W}{T_{PE}} = \frac{W}{T/4} = \frac{4}{T/W} = 7.27$$

$$\frac{1}{C_{\mu_{PE}}} = \frac{q}{T_{PE}/S} = \frac{q}{\frac{T_{PE}}{W} \cdot \frac{W}{S}} = \frac{q}{\frac{T}{W}\left(\frac{1}{4}\right)\frac{W}{S}} = \frac{q}{.55\left(\frac{1}{4}\right)80} = \frac{q}{11.0}$$

or

$$q = (11.0)\left(\frac{q}{T_{PE}/S}\right)$$

where $\dfrac{q}{T_{PE}/S}$ is obtained as illustrated in Figure 33.

Configuration	$\dfrac{q}{T_{PE}/S}$	q	V KEAS
Full Span Double Slotted Flaps	1.92	21.10	79.0
Inboard Double Slotted Flaps + Outboard Single Slotted Flaps with BLC	1.675	18.44	74.0
Full Span Triple Slotted Flaps	1.81	19.88	76.5
Inboard Triple Slotted Flaps + Outboard Single Slotted Flaps with BLC	1.60	17.60	72.0

The speeds are also shown graphically in the bar chart in Figure 34. It is seen that reductions in climbout speeds in the order of 2 knots (EAS) are obtained in going from double slotted flaps to triple slotted flaps, and that reductions of approximately 5 knots (EAS) are realized when BLC with a total of $C_{\mu_{AIL}} = .065$ is applied at the wing tips.

42
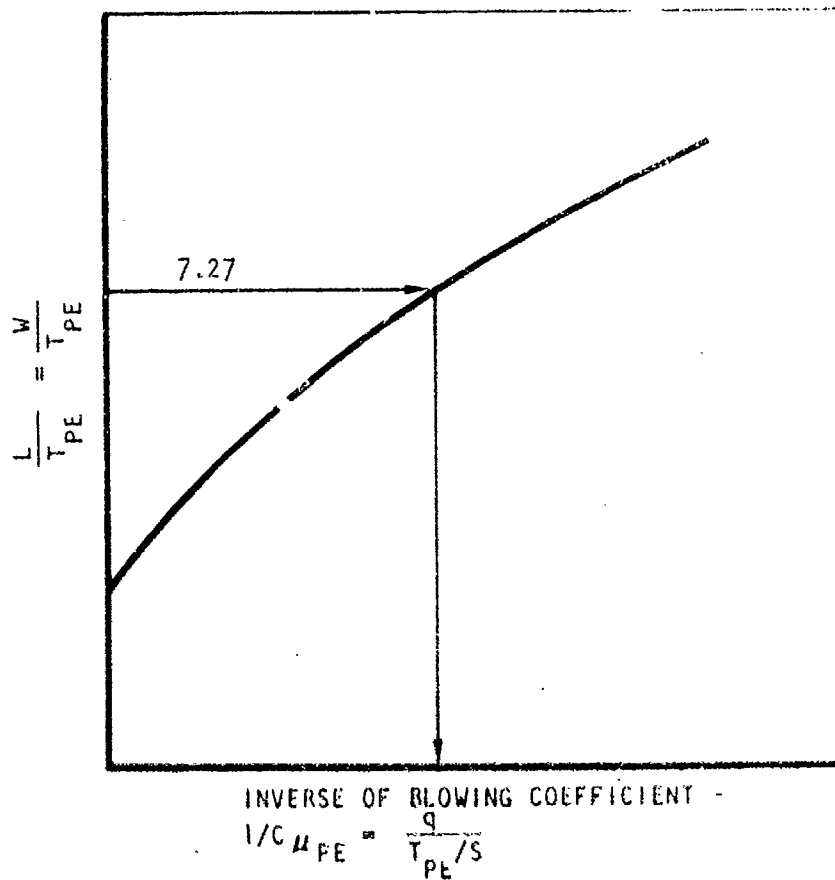
Figure 33. Determination of Blowing Coefficient When Weight and Thrust are Given

W/S = 80
T/W = 0.55

INBD DOUBLE-SLOTTED FLAPS
AND AILERONS WITH BLC

FULL-SPAN, DOUBLE-
SLOTTED FLAPS

INBD TRIPLE-SLOTTED
FLAPS AND AILERONS WITH
BLC

FULL-SPAN, TRIPLE-
SLOTTED FLAPS

0   20   40   60   80   100
EQUIVALENT AIRSPEED - V (KEAS)
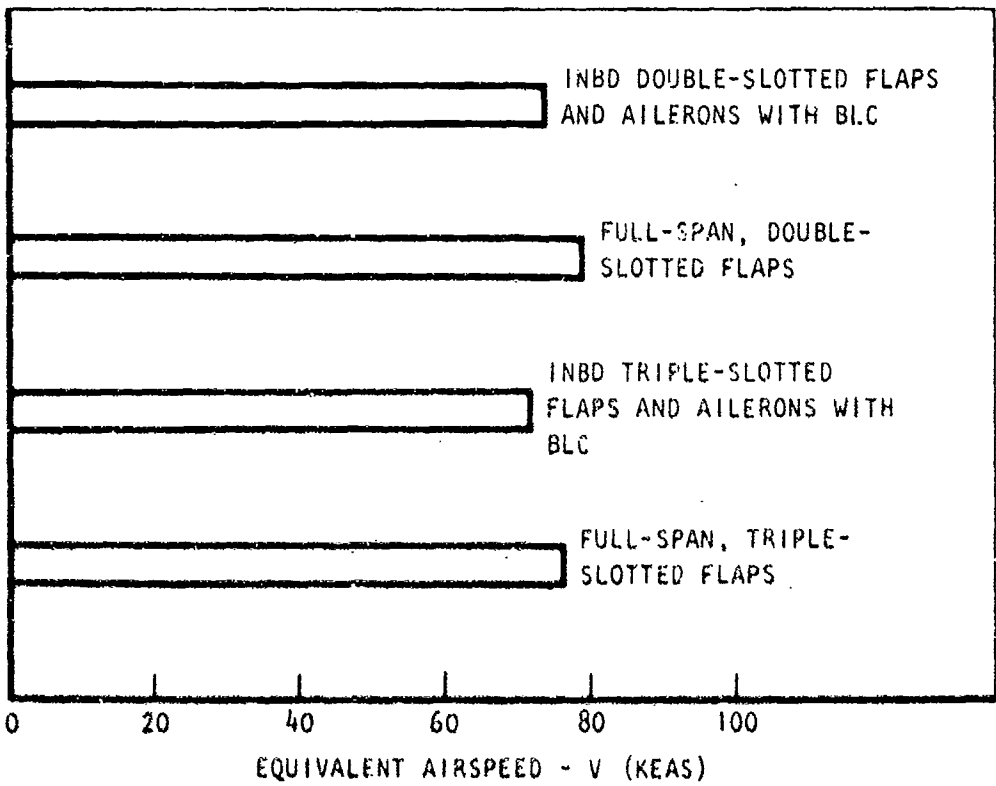
Figure 34. Comparison of Minimum Speeds for $\gamma = +3°$ With One Engine Failed

It should be noted that the above comparisons are made to obtain an impression of relative speeds. The actual climbout speeds may be somewhat different when additional safety margins in terms of speed and maneuver capability are considered. Also, it should be noted that T_{PE} is the static exhaust thrust and no influence of engine bleed air or gas extraction for BLC on engine weight is considered here, nor a difference in weight for the various flap geometries.

Furthermore it should be pointed out once more that these conclusions are drawn only on the basis of the ability to climb 3° and simultaneously meeting the safety margins. Conclusions drawn in Sections IV, V, and VI may overshadow those of the present section on the basis of other criteria. However, before arriving at these, hereafter the data basis and methodology used in the present section will be described first.

3.2 METHODOLOGY AND DATA BASIS

3.2.1 EFFECT OF SYMMETRIC AILERON BLC ON LIFT AND DRAG

The basic untrimmed lift and drag data in the previous section include cases with and without aileron BLC. With blown ailerons, symmetric BLC is needed to obtain the lift for which n = 1.3 and all engines operating. However, no test data for symmetric BLC were obtained from the wind tunnel test (GELAC 090), Reference (4), but estimates are derived here from asymmetric BLC from this test:

LIFT:

For $\delta_a = 30°$: ΔC_ℓ = .044 due to asymmetric BLC with $C_{\mu BLC}$ = .065 estimated from wind tunnel data (GELAC 090)

$$\Delta C_{L_{BLC}} = \Delta C_\ell \cdot \frac{b}{Y} = (.044)\, 2.74 = .121$$

This is the ΔC_L on one side with $C_{\mu\ BLC} = .065$ at that side. It is assumed that with blowing on both sides with half as much $C_{\mu\ BLC}$ per side the same total lift is obtained:

$$\Delta C_{L\ BLC} = + .12$$

or

$$\frac{\Delta L_{BLC}}{T_{PE}} = (.12) \frac{q}{T_{PE}/S}$$

The magnitude of this lift change is relatively insignificant, though not negligible.

DRAG:

The drag change due to BLC at the ailerons is estimated on the basis of Figure 35. The drag change can be treated as an incomplete thrust recovery of the thrust generated at the BLC nozzles.

If there were 100 percent thrust recovery, one would obtain a forward force change

$$\frac{\Delta F_x}{q S} = - \Delta C_D = C_{\mu\ BLC}$$

With loss in recovery it is obtained

$$\frac{\Delta F_x}{q S} = - \Delta C_D = C_{\mu\ BLC} - \frac{\partial \Delta C_{D\mu}}{\partial C_\mu} \cdot C_{\mu\ BLC}$$

or

$$\Delta C_D = - \left(1 - \frac{\partial \Delta C_{D\mu}}{\partial C_\mu} \right) C_{\mu\ BLC}$$

Figure 35 yields for $\delta_a = 30°$:

$$\Delta C_D = - (1 - .140)(0.065) = - .056$$

or

$$\frac{\Delta D}{T_{PE}} = (-.056) \frac{q}{T_{PE}/S}$$
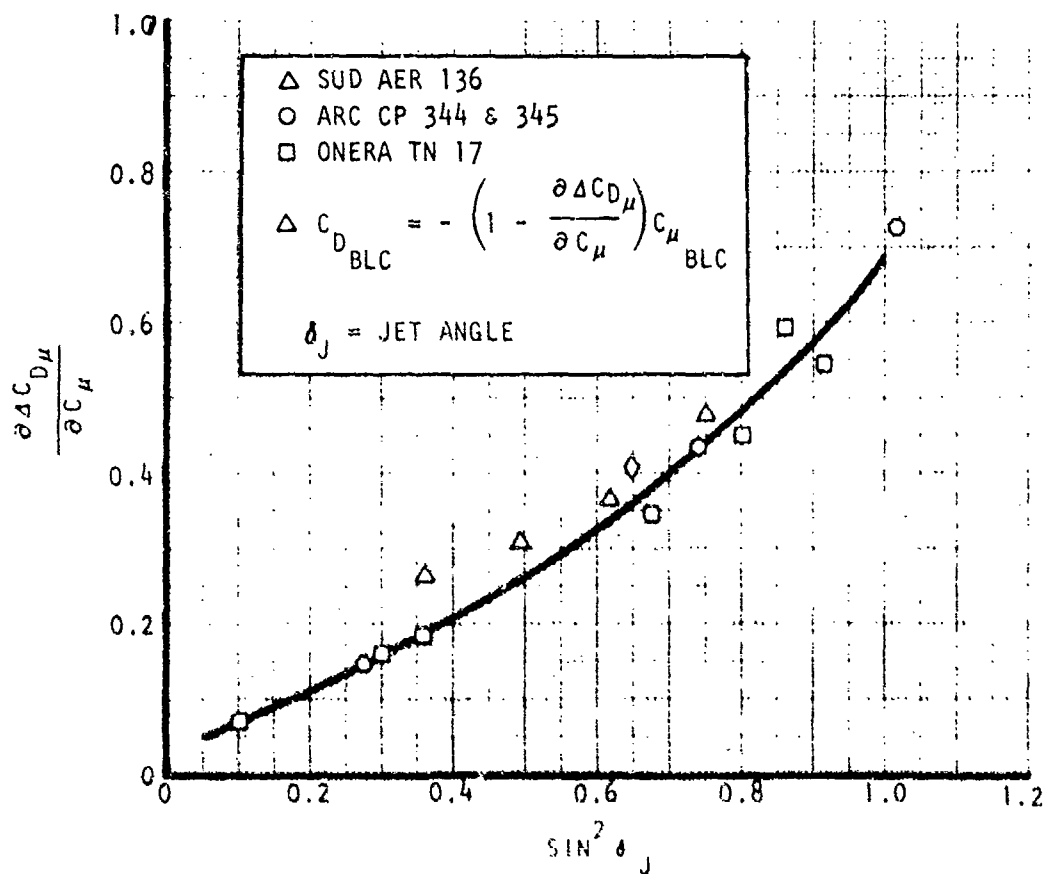
which is a significant magnitude.

46

Figure 35. Loss in Thrust Recovery Using BLC Flaps

Figure 35 is based on quasi two dimensional data.

BLC is applied only at the wing outer panels. Wings with BLC in this study are equipped with single slotted flaps at the outer panels, regardless whether the inboard flap is double slotted or triple slotted. The aerodynamic lift and drag data for these flap arrangements before BLC is applied are estimated and are shown in Figure 36 for a sample condition. Application of $\Delta D/T_{pE}$ and $\Delta L/T_{pE}$ from blowing yields then the basic drag polars with blowing used in the previous paragraph.

3.2.2 LIFT AND DRAG FROM ENGINE FAILURE, UNTRIMMED

The effect of engine failure on the lift, drag, rolling moment, yawing moment and pitching moment in the untrimmed condition must be known so that the trimmed lift and drag with control surface deflection can be assessed. In the present subsection the untrimmed lift and drag determination is described.

In general, the effect of engine failure may be known directly from wind tunnel data only for one or at best a few selected flap angles. At different flap angles an estimate must be made. In the present study only test data for the double slotted flap with deflection 25/50° are available. Estimates for the other deflections of this flap and for the triple slotted flap are made using the lift ratio:

$$\frac{\Delta L_{EF}}{\Delta L_p} = \frac{(\Delta L_p)_{3\,ENG}}{(\Delta L_p)_{4\,ENG}} - \frac{(\Delta L_p)_{4\,ENG}}{(\Delta L_p)_{4\,ENG}} = -\left[1 - \frac{(\Delta L_p)_{3\,ENG}}{(\Delta L_p)_{4\,ENG}}\right]$$

where ΔL_p is the increment of lift due to power effects with all engines operating, and ΔL_{EF} is the lift change due to engine failure. Figure 37 shows $(\Delta L_p)_{3\,ENG}/(\Delta L_p)_{4\,ENG}$ to be approximately .75 on the basis of these wind tunnel data, so that

$$\frac{\Delta L_{EF}}{\Delta L_p} = -.25$$

(SURFACE AT WINGTIP HAS EQUAL
DEFLECTION AS INBOARD FLAPS)

$$\delta_F = 50°$$
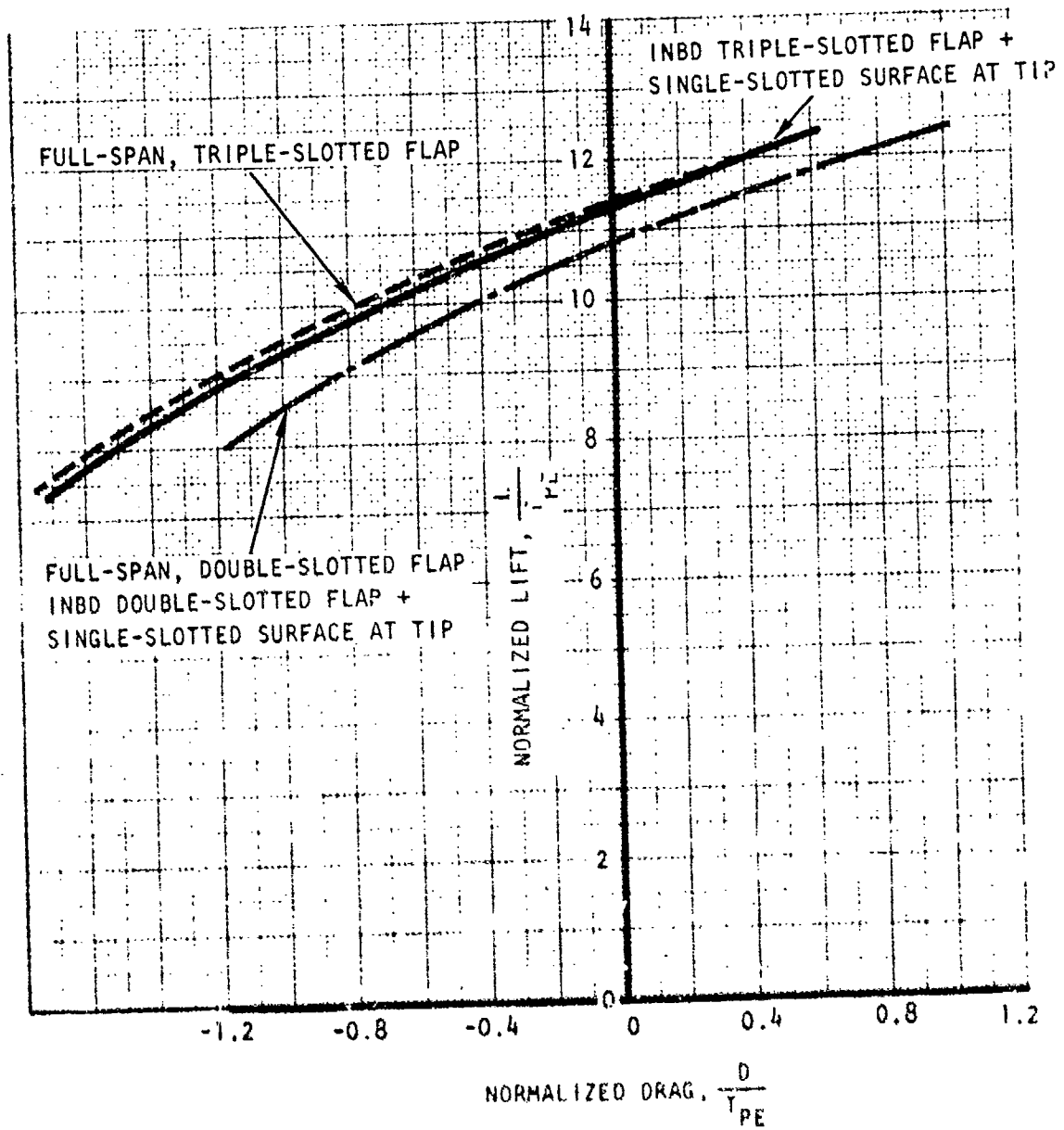
$$\frac{1}{C_{\mu_{PE}}} = \frac{q}{T_{PE}/S} = 2.00$$

Figure 36. Effect of Partial-Span, Triple and Double Slots
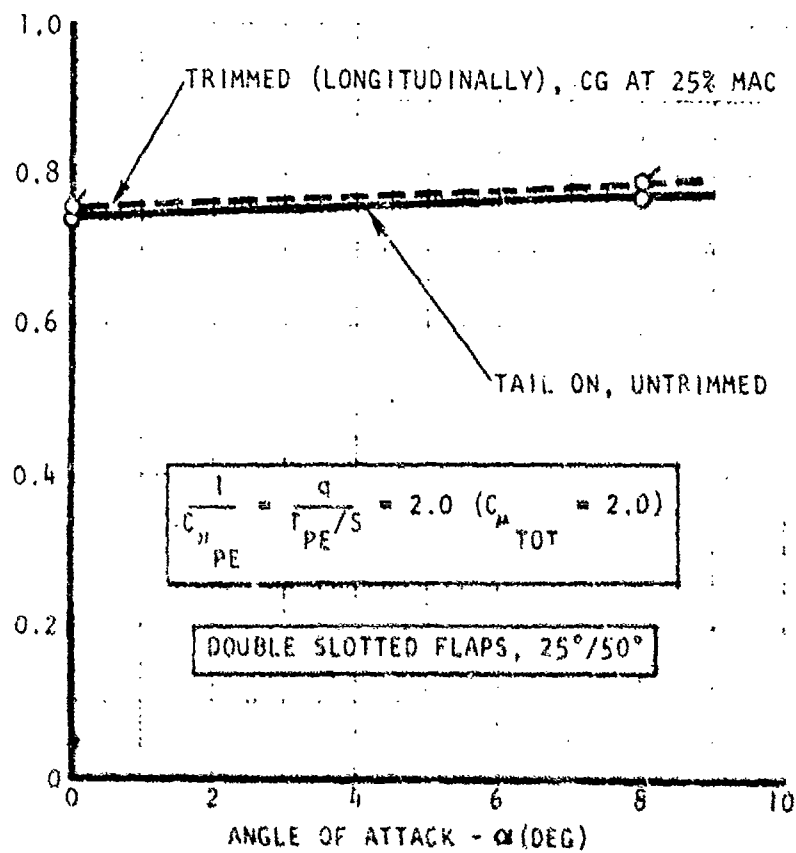
49

Figure 37. Effect of Outboard Engine Failure on Lift Due to Power

Similarly, the following is used here, by approximation

$$\frac{\Delta D_{EF}}{\Delta D_p} = -.25$$

and

$$\frac{\Delta M_{EF}}{\Delta M_p} = -.25$$

The lift and drag changes are added onto the lift and drag of the wind tunnel data for all engines operation (AEO) and results are shown in Figures 7 through 18 and indicated as critical engine failed (CEF).

3.2.3 EFFECT OF ENGINE-OUT ROLLING MOMENT AND ROLL CONTROL

(a) Engine Failure Moment

The rolling moment due to engine failure must be trimmed out using roll control or roll trim devices which in turn introduce additional lift, drag, and pitching moment changes.

The magnitudes of the untrimmed rolling moment coefficient resulting from the critical outboard engine failure is shown in Figure 38 as a function of the lift increment ΔC_{Lp} that is obtained from external blowing. The magnitudes are based on a wind tunnel data analysis for various flap settings and thrust coefficients, see Figure 39. Angles of attack greater than 18° are excluded because these angles are greater than the one-engine-out stall angle where the rolling moments are excessive as seen in Figure 40.

The engine failure not only produces a rolling moment, but also a yawing moment. When this yawing moment is trimmed out by using rudder, an additional rolling moment is generated which generally has the same sign. The incremental rolling moment and the yawing moment is:

$$\Delta \mathcal{L} = \Delta C_{\ell} \, q S b = Y_T \cdot z_v$$

$$\Delta \mathcal{N} = \Delta C_n q S b = Y_T \cdot \ell_v = \Delta D \cdot Y$$

51

OUTBOARD ENG FAILED

$\alpha < 18°$
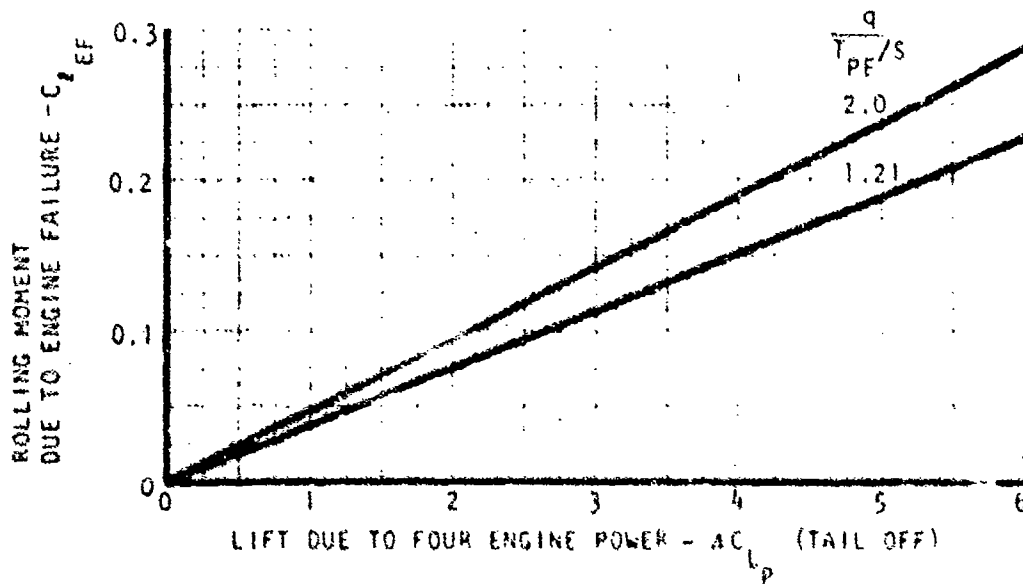

Figure 38. Rolling Moment Due to Engine Failure Versus Tail-Off Lift Due to Power

52

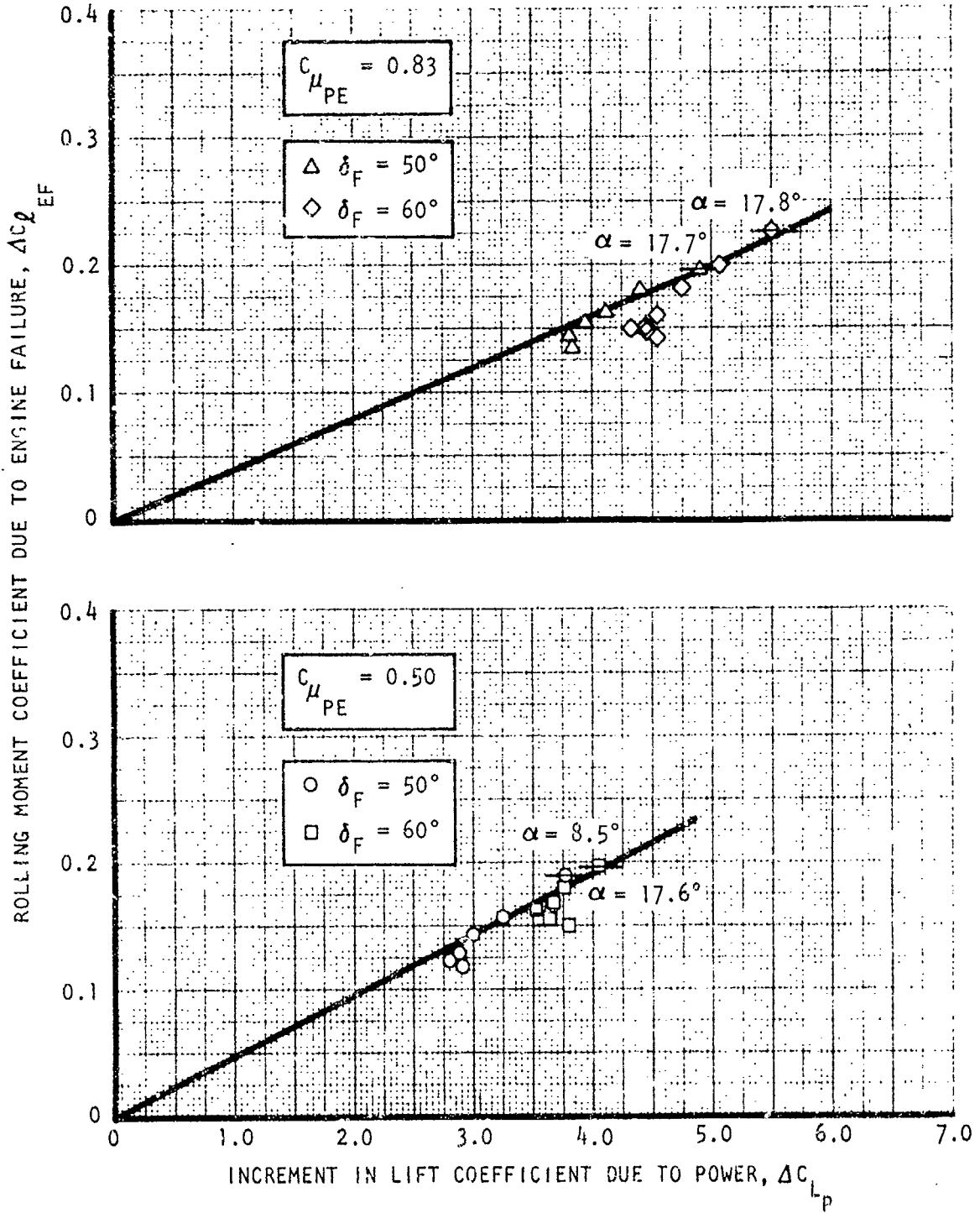SOLID SYMBOL:
HIGHEST α TESTED BELOW STALL

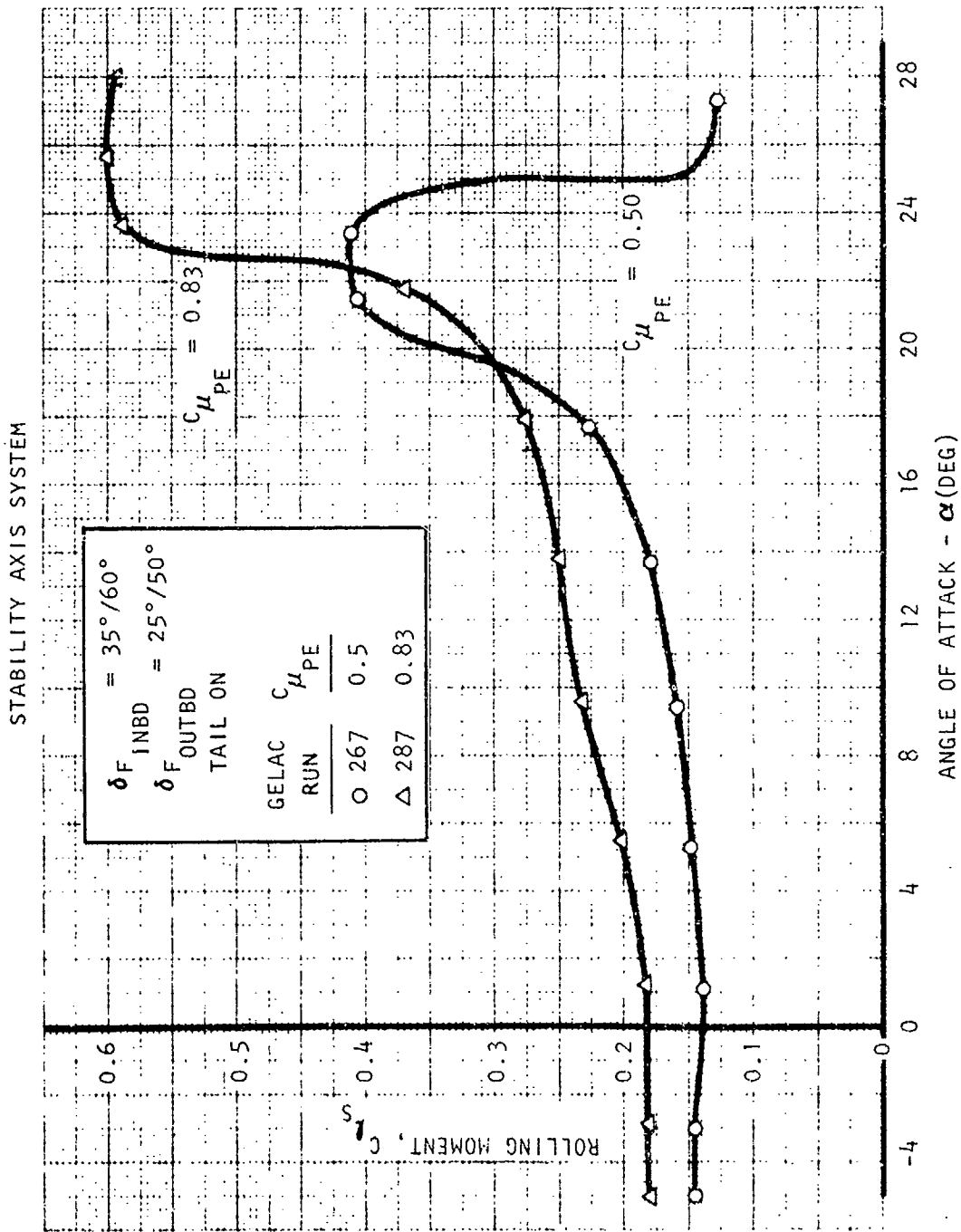Figure 39. Rolling Moment Due to Outboard Engine Failure

Figure 40. Roll Due to Outboard Engine Failure

where Y_T is the side force on the tail, and Z_V and l_V the location of the tail center of pressure above and behind the airplane c.g. in the stability axis system. The symbol ΔD represents the drag change due to engine failure, located at a lateral distance Y:

$$\Delta D = \left(C_{D_{TOT.}} - C_{D_{P.O.}}\right) \frac{q}{2} S\,(.25) = \Delta C_{D_P} \frac{q}{2} S\,(.25)$$

Elimination of Y_T yields

$$\frac{\Delta C_l}{\Delta C_{D_P}} = \frac{Y}{b} \cdot \frac{Z_V}{l_V}(.25)$$

This relation is plotted in Figure 41 as a function of angle of attack and is used in the determination of the total rolling moment.

(b) Lift Loss Due to Roll Control

This total rolling moment can be trimmed by a number of roll control devices, such as:

Roll control spoiler actuation
Aileron deflection
Asymmetric aileron BLC
Differential flap

Of these, the differential flap is not used in the present document.

Actuation of roll control devices generally results in an important lift change and drag change of the STOL aircraft. The lift change due to spoilers is illustrated in Figure 42 for the double slotted flap. Herein, the lateral center of pressure location is 73 percent semispan for the tip spoiler, 47 percent for the mid-span spoilers, and 27 percent for the inboard spoilers. (The location of the spoilers is seen in Figure 1).

In order to decrease the lift loss, other devices are added. Adding ailerons yields a slightly larger roll control for the same total lift loss, see Figure 43. Using aileron BLC in addition to aileron deflection improves the characteristics considerably, which is also shown in that figure.

55

STABILITY AXIS SYSTEM

$$\frac{\Delta C_{\ell}}{\Delta C_{D_P}} \ OR \ \frac{\Delta \frac{\ell}{T_{PE} b}}{\left(\frac{\Delta D_P}{T_{PE}}\right)}$$

ROLLING MOMENT DUE TO RUDDER
DRAG CHANGE DUE TO FOUR ENGINE POWER

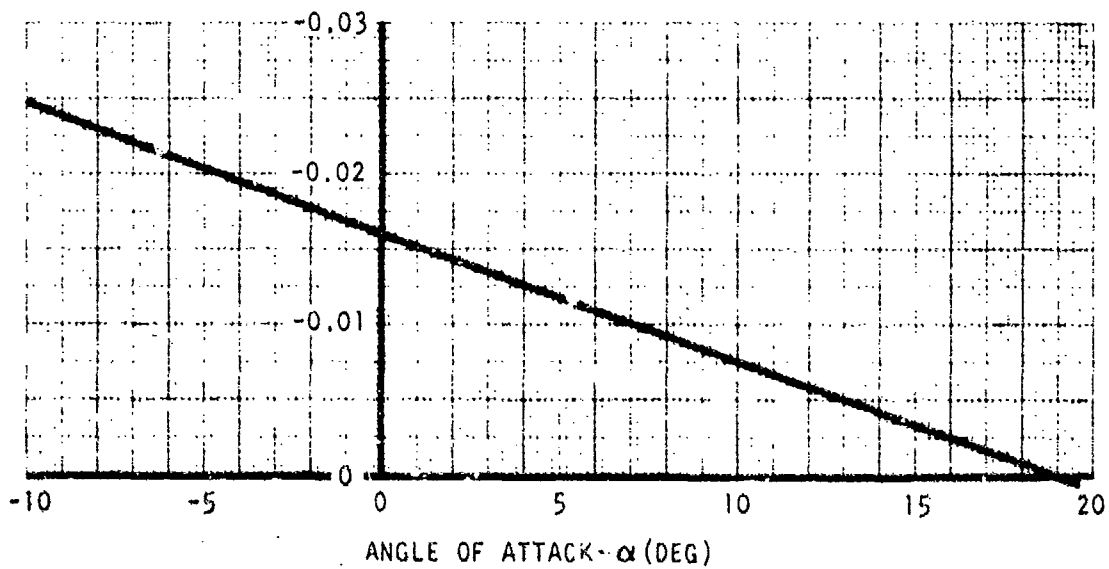ANGLE OF ATTACK - α (DEG)

Figure 41. Effect of Rudder for Trimming in Yaw on Rolling Moment Due to Engine Failure

56

NOTE:
AILERON DEFLECTION
OR AILERON BLOWING
NOT INCLUDED
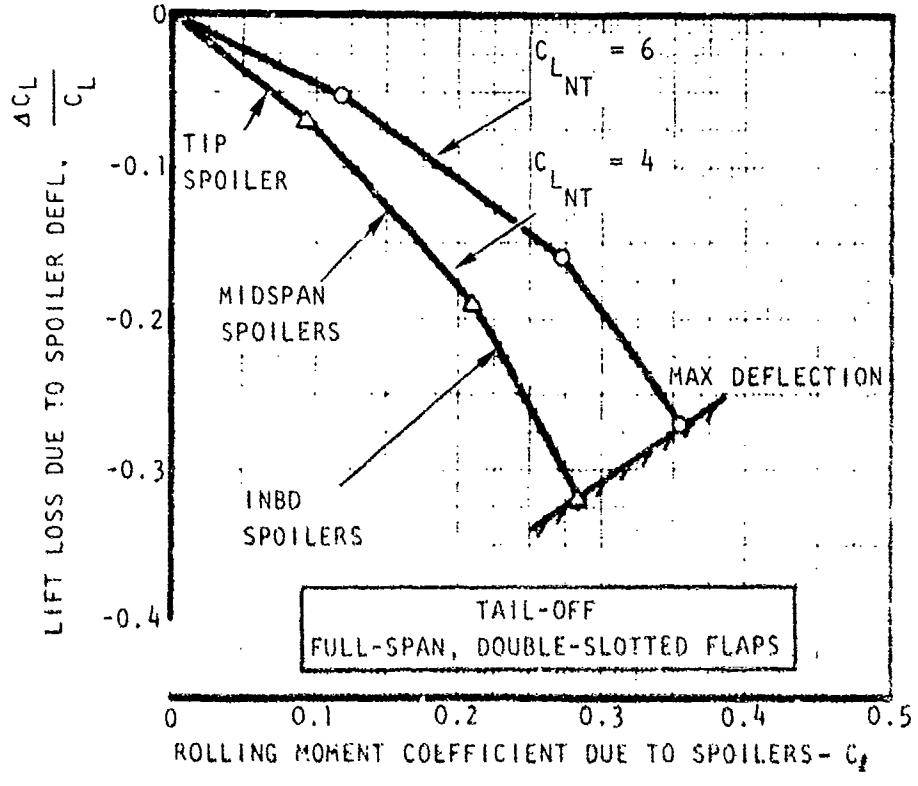
NOTE:
APPLY TO FOUR-ENGINE
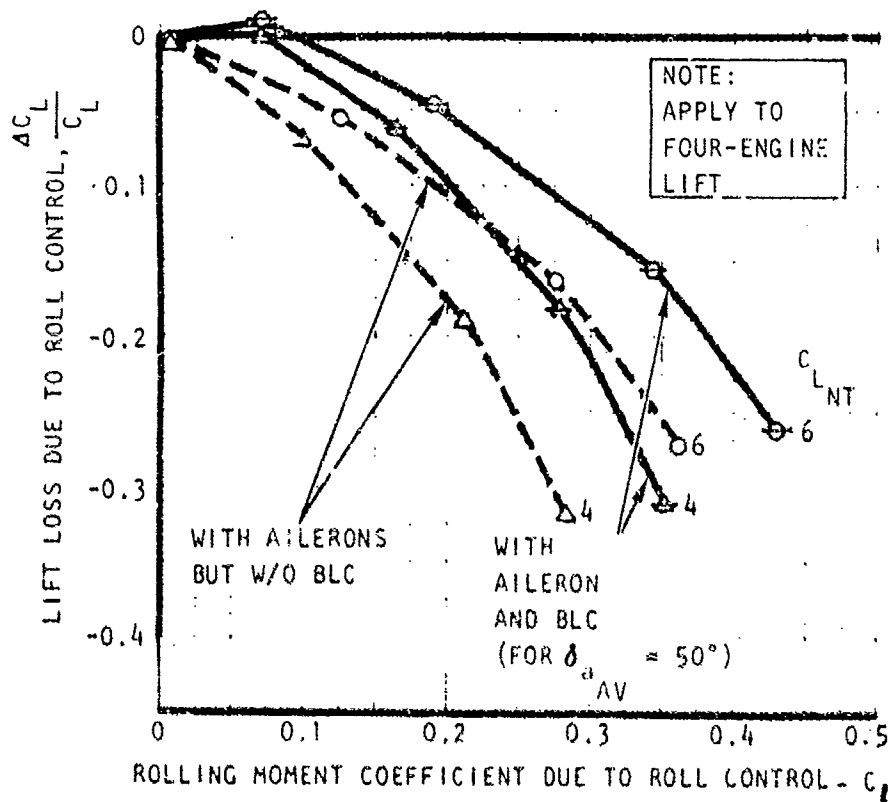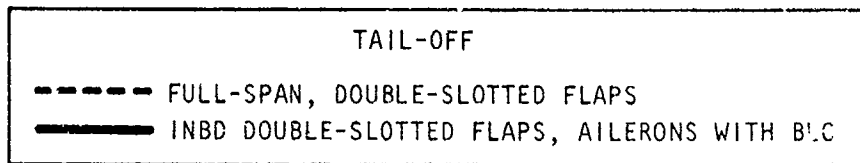LIFT

Figure 42. Lift Loss Due to Spoiler Deflection

Figure 43. Lift Loss Due to Roll Control

58

Similar lift loss characteristics of spoilers plus ailerons but for triple slotted flaps are shown in Figure 44. The rolling moments generated by spoilers of triple slotted flaps are substantially less, which will be described later. The lateral c.p. locations for the spoiler forces are the same as those for the double slotted flap. Aileron BLC is not used in conjunction with full span triple slotted flaps and is for this reason not shown in this figure.

Use of inboard triple slotted flaps, and single or double slotted flaps at the tips results in characteristics presented in Figure 45. Data with and without aileron BLC are shown there.

In the above figures, the effect of BLC is shown for a surface deflection of 50°. In case the surface deflection is 30° (such as a lesser aileron deflection with blowing) only 80 percent of the BLC effect is used.

(c) Drag and Pitching Moment Due to Roll Control

Operation of roll control devices affects the drag characteristics of the aircraft.

Opening the spoilers decreases not only the lift, but also decreases the drag when the aircraft angle of attack is high. However, a drag increment is obtained when the angle of attack is low. In the present study the relation

$$\Delta C_{D_{SP}} = \left(C_D - C_{D \, AT \, \alpha = 0} \right) \frac{\Delta C_{L_{SP}}}{C_L}$$

is used, based on Figure 46a.

The effect of aileron deflection on drag change is negligible with and without aileron BLC.

The tail off pitching moment change is computed from

$$\Delta C_{m_{SP}} = \frac{\Delta C_m}{\Delta C_L} \cdot \Delta C_{L_{SP}}$$

where $(\Delta C_m / \Delta C_L)_{SP}$ is obtained from Figure 46b. This is also based on the wind tunnel data for angles of attack of interest. The pitching moment is needed to obtain the proper trimmed lift.

59

TAIL-OFF
FULL-SPAN TRIPLE SLOTTED FLAPS
WITH AILERONS (WITHOUT BLC)
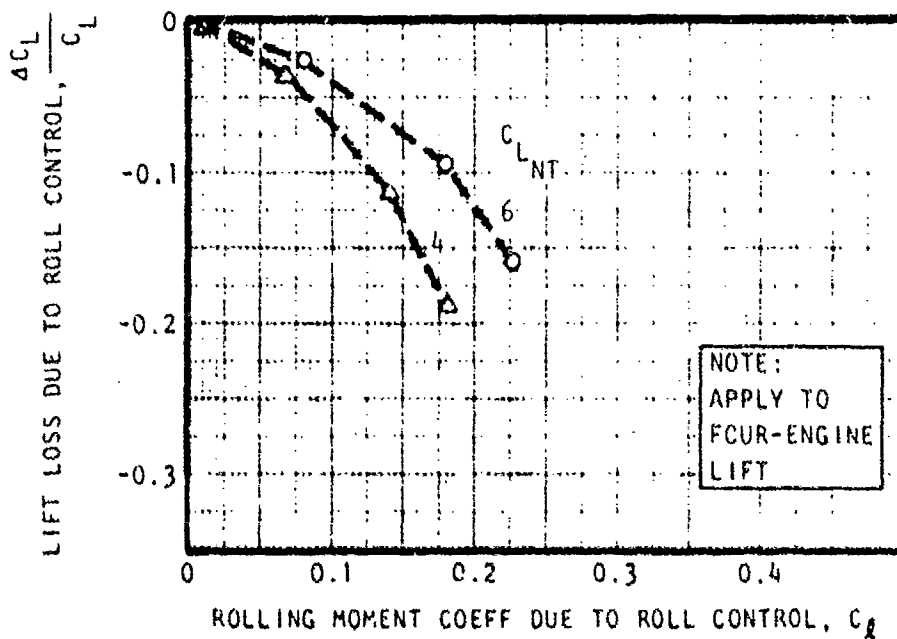
Figure 44. Lift Loss Due to Roll Control

TAIL OFF
SINGLE-SLOTTED FLAPS AT TIP WITH BLC
TRIPLE-SLOTTED FLAPS INBOARD OF TIP
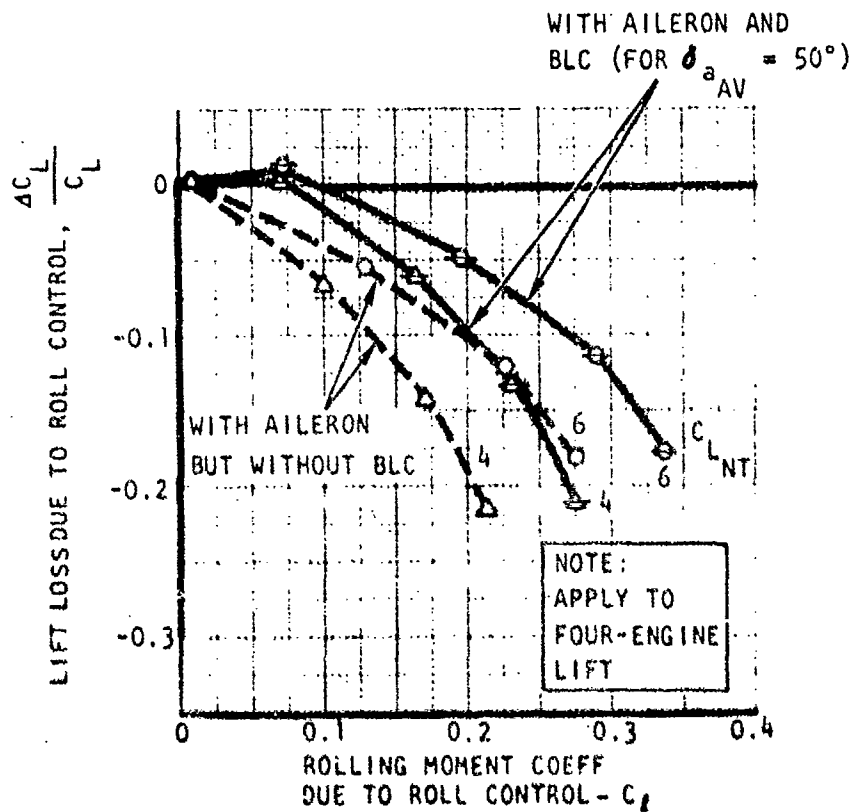
Figure 45. Lift Loss Due to Roll Control

61
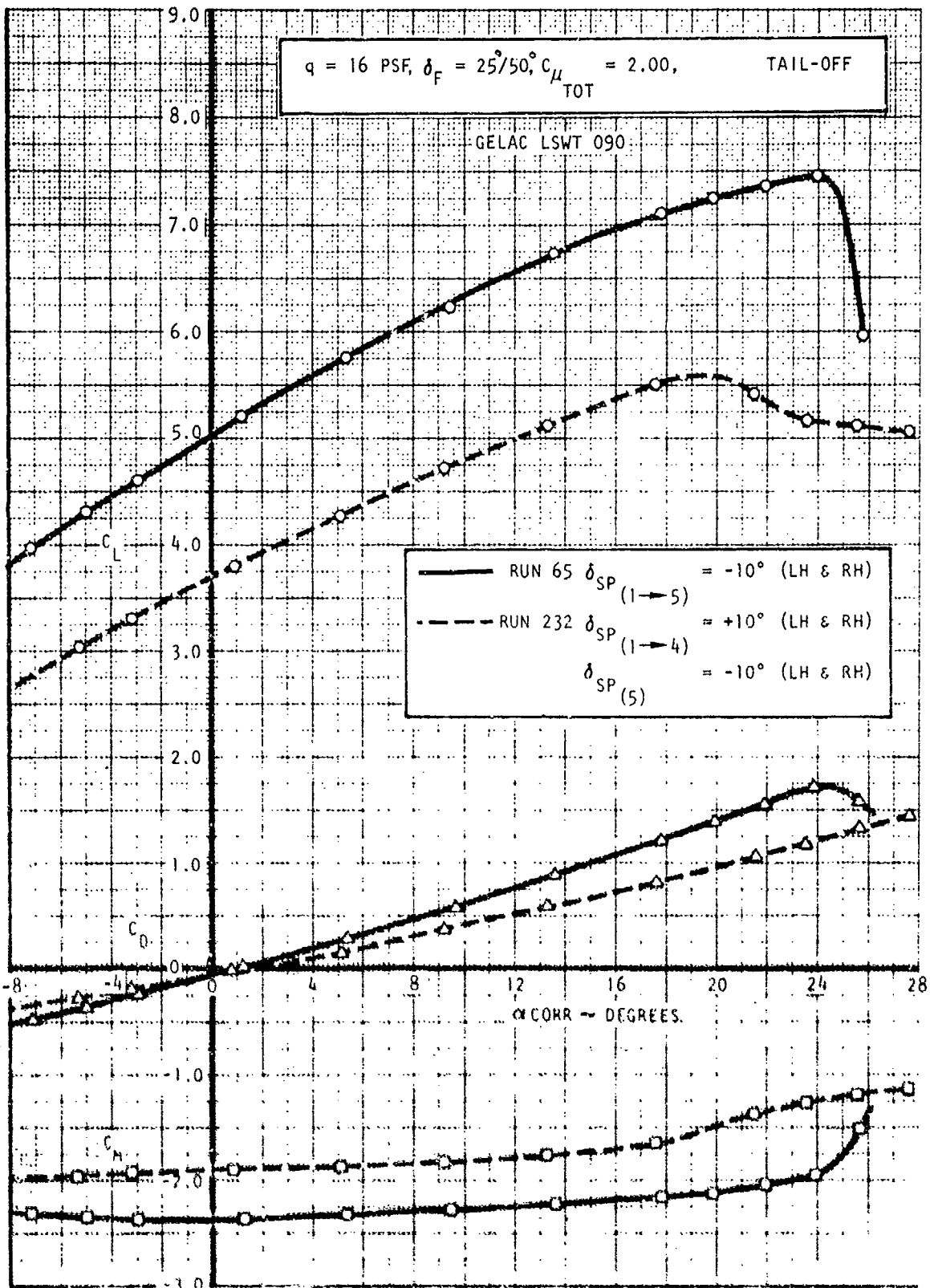
Figure 46a. Effects of Symmetric Spoiler Deflection on Longitudinal Characteristics

The figure shows plots with the following labeled data:

q = 16 PSF, δ_F = 25/50°, $C_{\mu_{TOT}}$ = 2.00,   TAIL-OFF

GELAC LSWT 090

RUN 65 $\delta_{SP_{(1 \to 5)}}$ = -10° (LH & RH)

RUN 232 $\delta_{SP_{(1 \to 4)}}$ = +10° (LH & RH)

$\delta_{SP_{(5)}}$ = -10° (LH & RH)

Vertical axes: C_L, C_D, C_M

Horizontal axis: α CORR ~ DEGREES.

TAIL-OFF

GELAC LSWT - 090

Figure 46b. Effect of Spoiler Deflection on Pitching Moment

63

3.2.4 EFFECT OF PITCH TRIM ON LIFT AND DRAG

The tail off pitching moment $C_{m_{NT}}$ $q S \bar{c}$ used in the present study pertains to a forward c.g. location of 25 percent MAC. Trimming out this pitching moment results in a lift change of the aircraft amounting to

$$\Delta C_L = \frac{\bar{c}}{\ell_H} \, C_{m_{NT}} = .285 \, C_{m_{NT}}$$

The coefficient $C_{m_{NT}}$ includes the pitching moment contribution of the roll control devices for roll trim in case an engine has failed.

In addition to the lift change from the tail, also a trim drag change is used, because the tail lift vector is inclined with respect to the horizontal by the downwash. The drag correction is approximately
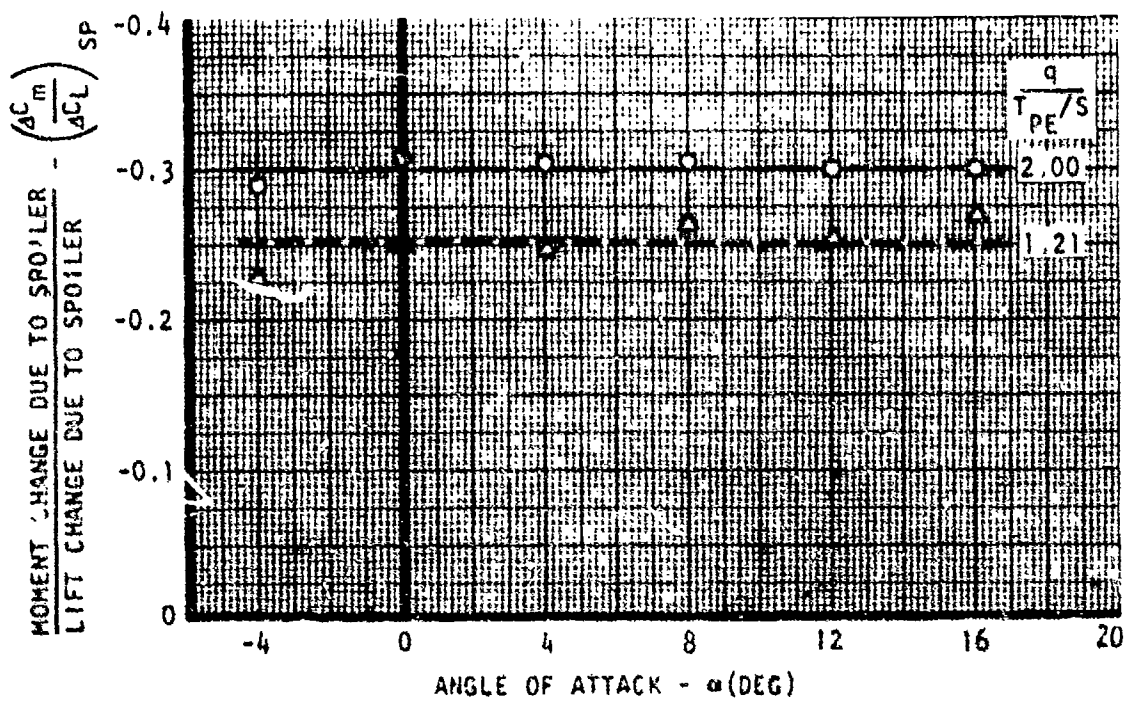
$$\Delta C_D = \Delta C_L \cdot \frac{\varepsilon^\bullet}{57.3}$$

Where an average ε of 12 degrees was used. In general this term results in a reduction of drag because ΔC_L is negative.

64

Section IV

COMPARISON OF ROLL ACCELERATION
WITH ALL ENGINES OPERATING

4.1 REQUIRED AND AVAILABLE ROLLING MOMENTS VS C_L

One criterion for selecting a roll control system of STOL aircraft is whether it meets specified roll acceleration criteria.

The criterion listed in MIL-F-83300 (Reference 1) requires a bank angle of 30 degrees to be reached in 1.8 seconds for Level 1. Reaching this bank angle depends on the manner or time sequence with which the pilot generates the control input. Because this time sequence is not specified in the above reference, NASA TND-5594 will be used as a guideline (Reference 2). This reference uses a lag of 0.1 second before the control surfaces begin to move after pilot initiation. Full control is achieved through a 0.3 second ramp function. In this analysis, the total control input time of 0.4 second is assumed to include aerodynamic lag; which is apropos of the selected rapid response slot lip spoiler system. Using this time sequence, as shown in Figure 47, and a typical roll time constant of $\tau_R = 0.7$ for STOL transports, an initial acceleration capability of

$$\frac{\mathcal{L}}{I_{xx}} = \ddot{\phi}_o = 0.825 \text{ rad/sec}^2$$

is needed. Herein, $\mathcal{L}$ is the rolling moment due to roll control input (in ft/lbs), and I_{xx} is the rolling moment of inertia (in pounds ft-sec^2).

It may be noted that the requirement in AGARD 408 (Reference 3) to reach a bank angle of 10 degrees in one second results in a very compatible acceleration requirement, i.e., $\ddot{\phi} = 0.855$, using the same time sequence and time constant. However, the MIL-SPEC value of 0.825 will be used here.

The requirement can be rewritten using the following relation:

$$C_\ell \, q \, Sb \geq \ddot{\phi}_o \cdot I_{xx}$$

$$C_\ell \, \frac{w/s}{C_L} Sb \geq \ddot{\phi}_o \cdot I_{xx}$$

or

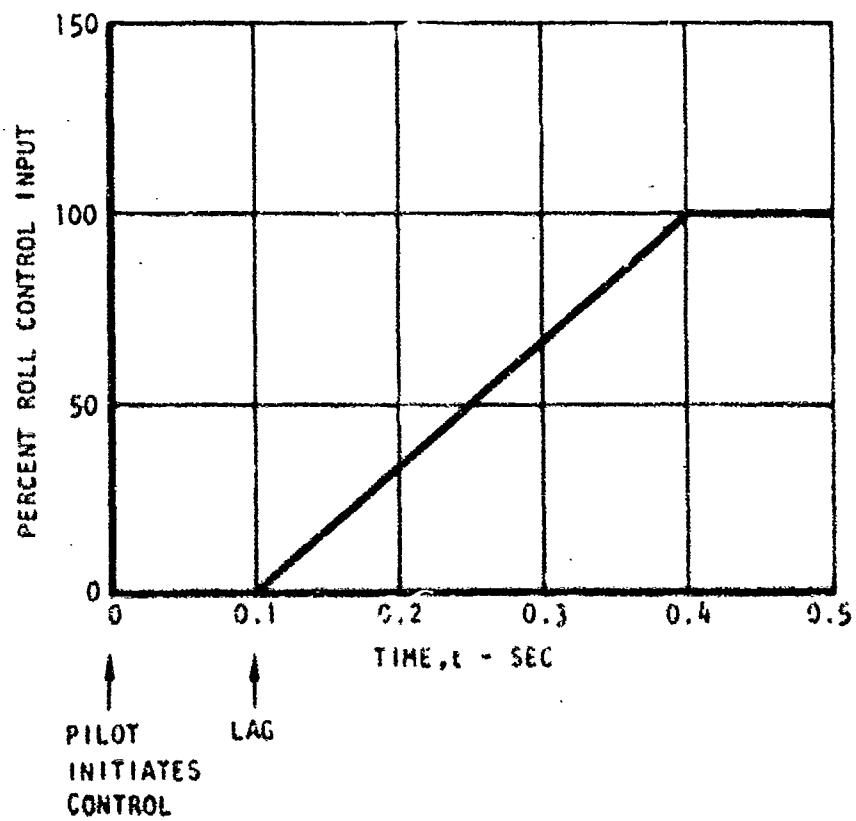$$\frac{C_\ell}{C_L} \geq \frac{\ddot{\phi}_o}{\left(\frac{W \cdot b}{I_{xx}}\right)}$$

65

Figure 47. Pilot Roll Control Input Versus Time

Substituting such typical values as W = 122,000 lbs., b = 116 ft, I_{xx} = 1200 ft. lbs. sec.^{2}, this yields

$$\frac{C_\ell}{C_L} \geq 0.070$$

This relationship is plotted as the requirement in Figures 48 through 51, where it is compared with the available roll control for various geometries. These geometries include ailerons in all cases and use additionally:

Figure	Geometry
48	Full span double slotted flap. Control with spoilers, no BLC
49	Inboard double slotted flap, outboard single slotted flap, control with spoilers and BLC
50	Full span triple slotted flap. Control with spoilers, no
51	Inboard triple slotted flap, outboard single slotted flap. Control with spoilers, and BLC.

Triple and double slotted flaps are included in the comparison because the roll control spoiler effectiveness depends on the type of flap used.

A comparison of speeds (for a sample wing loading of W/S = 80) where the Level 1 roll acceleration requirement is satisfied is presented in Figure 52. It is seen that it is possible to provide adequate roll control for all geometries considered in the STOL speed regime of interest (70 to 65 knots), except for the full span triple slotted flaps.

The available roll control from spoilers is described in the next subsection. The reason for the inadequate roll performance for that case is found in the deterioration of the spoiler effectiveness when going from double to triple slotted flaps, which is also described in the next subsection.
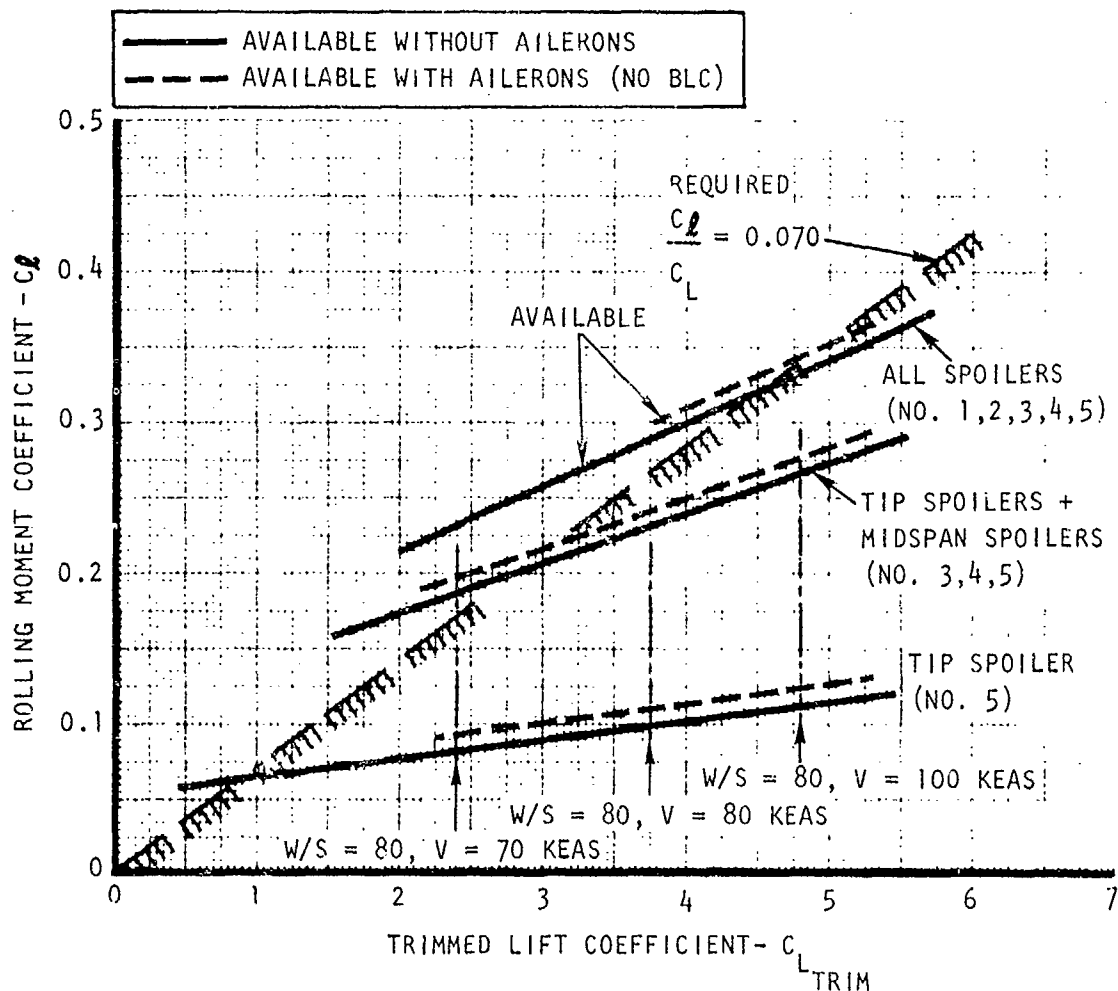
Figure 48. Required and Available Rolling Moment Coefficient, Full-Span, Double-Slotted Flaps Without Aileron BLC
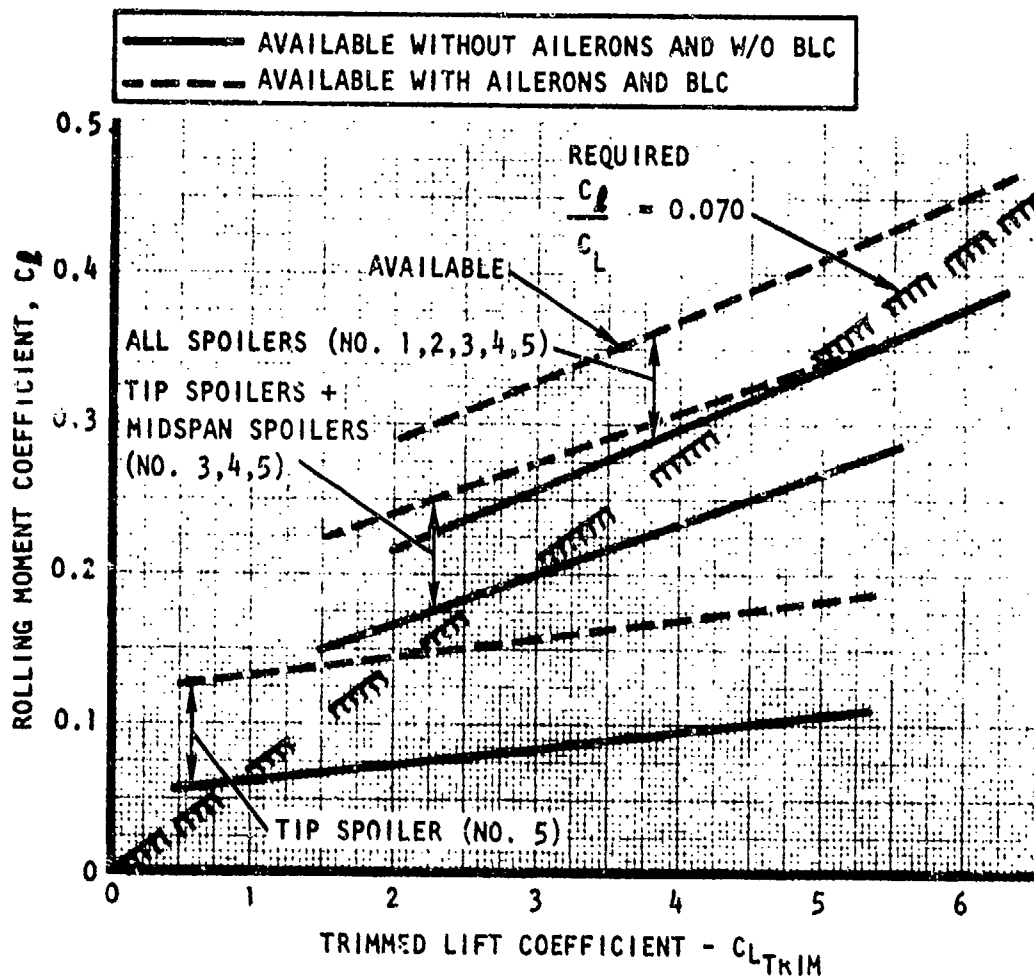
68

LEVEL 1 (ALL ENGINES OPERATING)

Figure 49. Required and Available Rolling Moment Coefficient
Inboard Double-Slotted Flaps, Ailerons With BLC
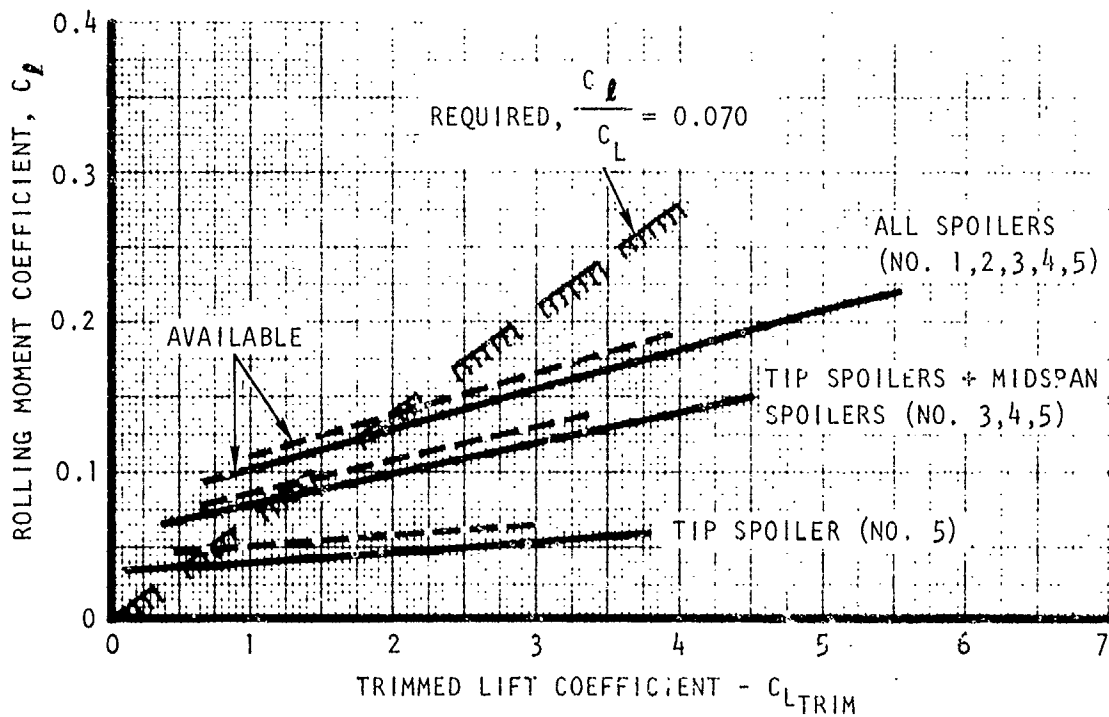
69

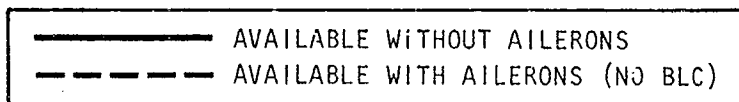LEVEL 1 (ALL ENGINES OPERATING)

————————	AVAILABLE WITHOUT AILERONS
— — — — — —	AVAILABLE WITH AILERONS (NO BLC)

Figure 50. Required and Available Rolling Moment Coefficient Full-Span, Triple-Slotted Flaps Without Aileron BLC

70
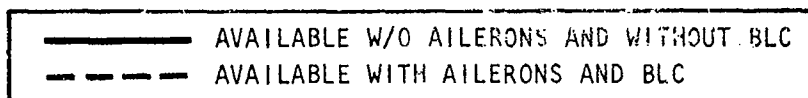
Figure 51, Required and Available Rolling Moment Coefficient Inboard Triple-Slotted Flaps, Ailerons with BLC

71

LEVEL 1
(ALL ENGINES OPERATING)

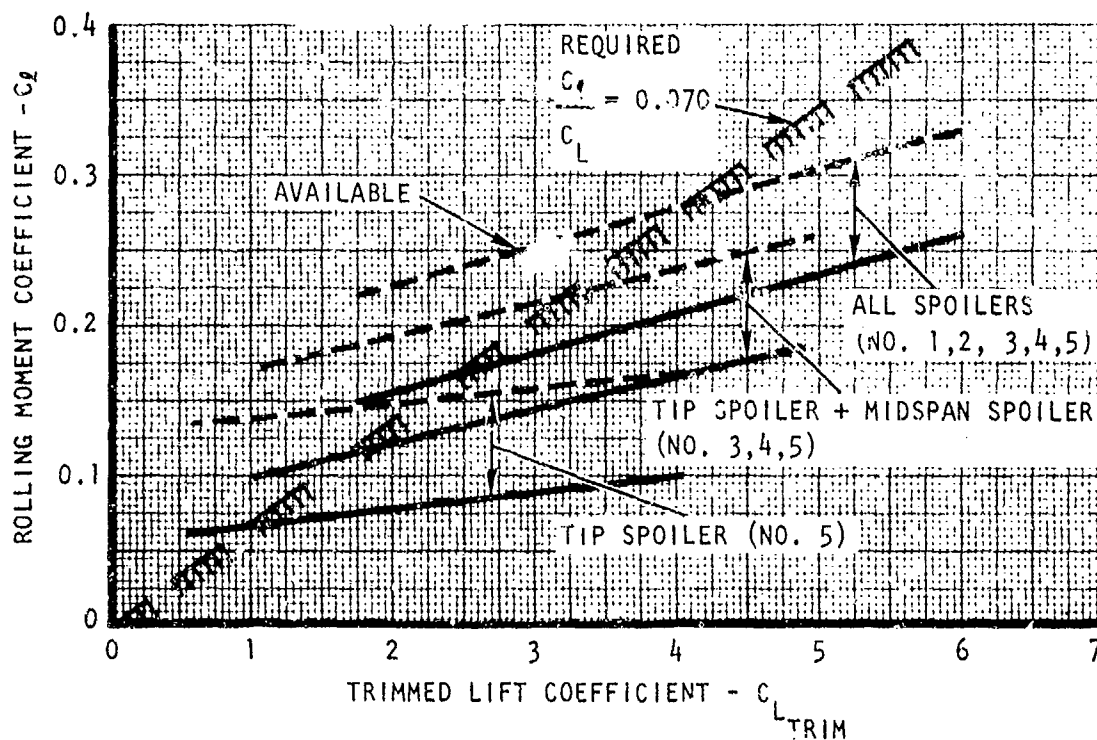SPOILERS ONLY AT MIDSPAN AND AT TIP

SPOILERS FULL SPAN

INBD DOUBLE-SLOTTED FLAPS,
AILERONS WITH BLC

FULL-SPAN, DOUBLE-
SLOTTED FLAPS

INBD TRIPLE-SLOTTED
FLAPS, AILERONS
WITH BLC

FULL-SPAN,
TRIPLE
SLOTTED FLAPS

EQUIVALENT AIRSPEED - V (KEAS)

Figure 52. Comparison of Speeds at Which Required Roll Accleration is Met

72

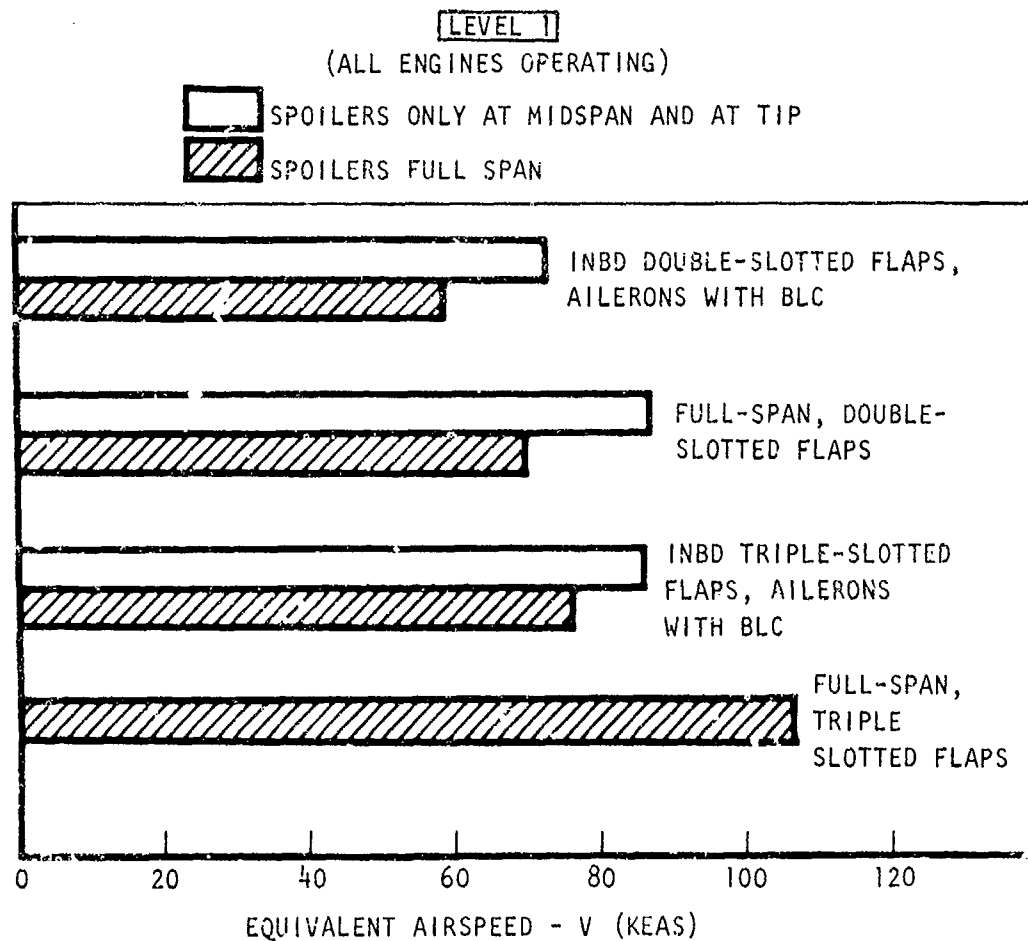## 4.2 METHODOLOGY AND DATA BASIS

4.2.1 SPOILER EFFECTIVENESS

The spoiler effectiveness used in the previous section for double slotted flaps is given here in Figures 53, 54, and 55, except that in the previous section a trimmed aircraft lift coefficient is used, whereas in the present section the data are presented in terms of the tail-off lift coefficient ($C_{L_{NT}}$, NT = no tail), The conversion from the trimmed condition to the tail-off condition is made using $C_{L_{trim}} = .88 \ C_{L_{NT}}$, based on Figures 56 and 57, and a forward c.g. location of 25 percent MAC.

The roll control data given here are based on wind tunnel analysis plots presented in Figures 58 and 59, which give rolling moment coefficients for various spoiler panels and various amounts of external blowing. One figure gives data for 4-engine operation, the other for 3, but the rolling moments can probably be used from either case since the spoilers in both cases are operated on the side where no engine has failed.

An interesting facet of the rolling moment coefficient shown for any given spoiler configuration is the fact that it is only a function of the wing lift coefficient, regardless whether this lift coefficient is varied with angle of attack or external blowing. In the present analysis this observation is extended here to also include a variation of lift coefficient with deflections of the flap as well.

The above Figures 58 and 59 are based on double slotted flaps only. The effectiveness of the spoiler deflection is reduced to approximately 60 percent when triple slotted flaps are used in comparison with double slotted flaps, see Figure 60. This is based on a single wind tunnel test comparison (GELAC 090) of two flaps with approximately equal lifting capability and should be used with caution. Because of lack of evidence to the contrary, this reduction is used in the present study for the appropriate flap panels.

The data in Figures 58 and 59 are given as a function of the tail-on untrimmed lift coefficient. The correction factor to obtain tail off lift coefficients is given in Figure 61.
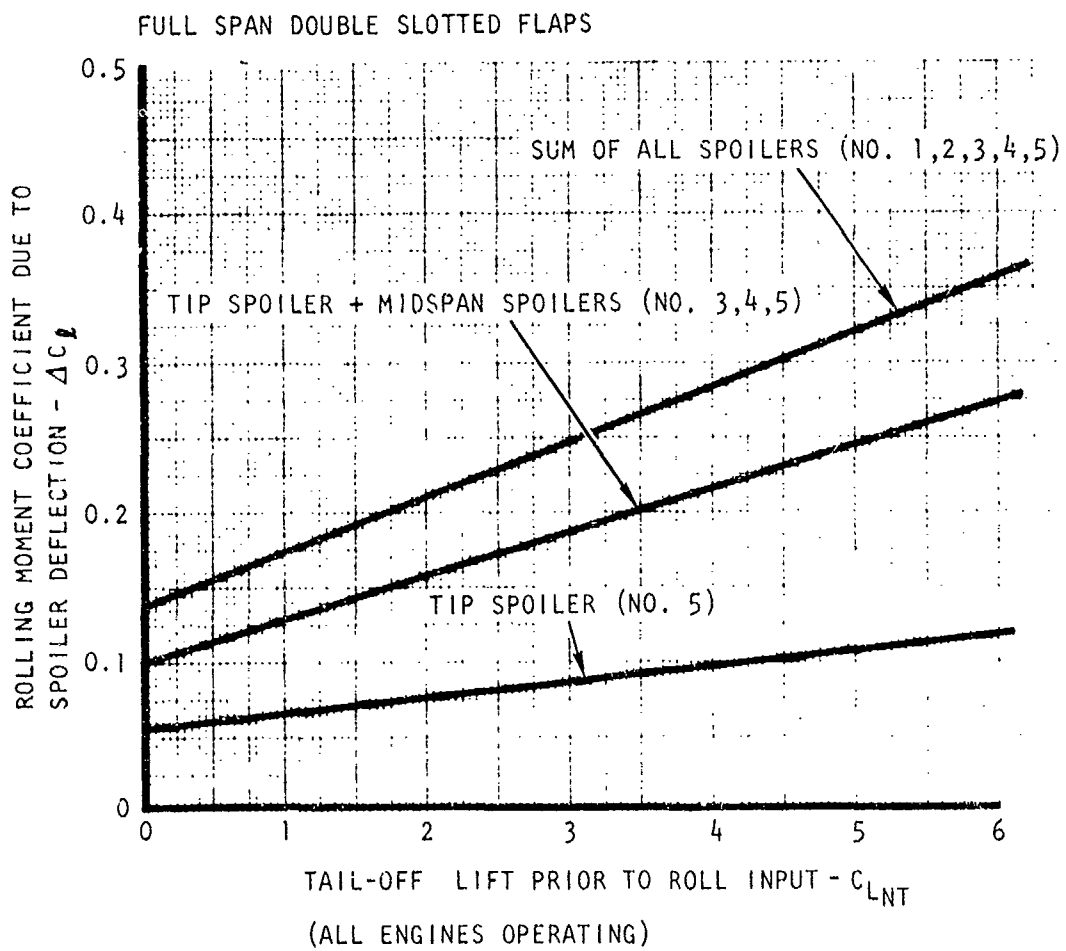
73

Figure 53. Available Roll Control From Spoilers Versus Tail-Off Lift
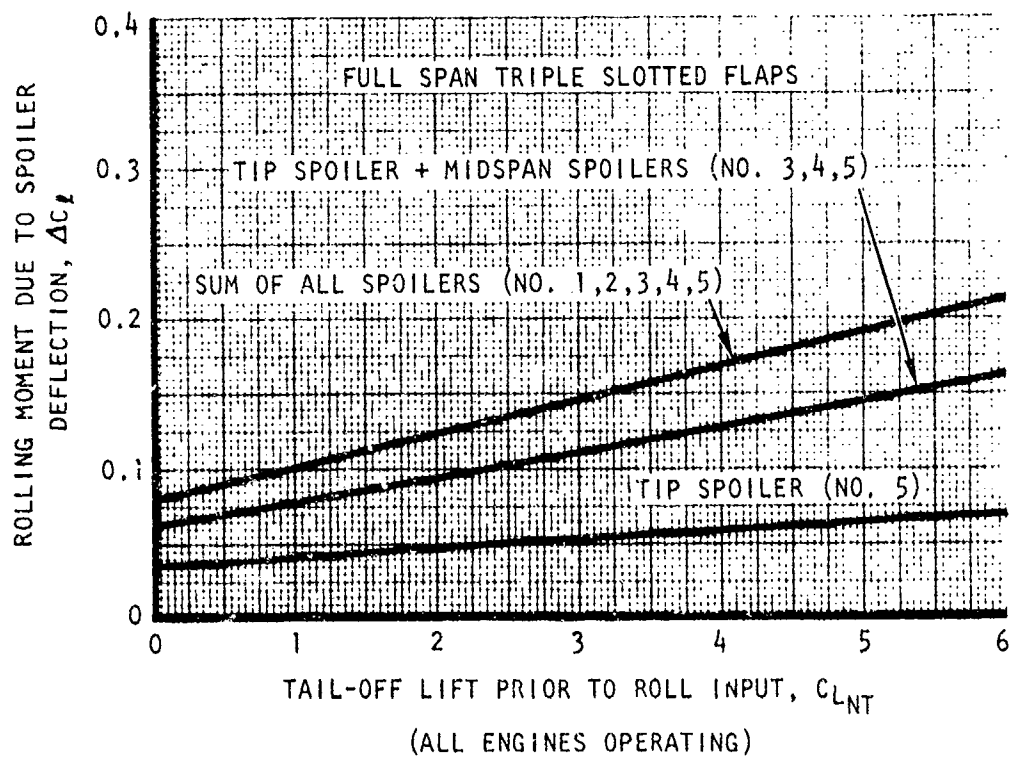
74

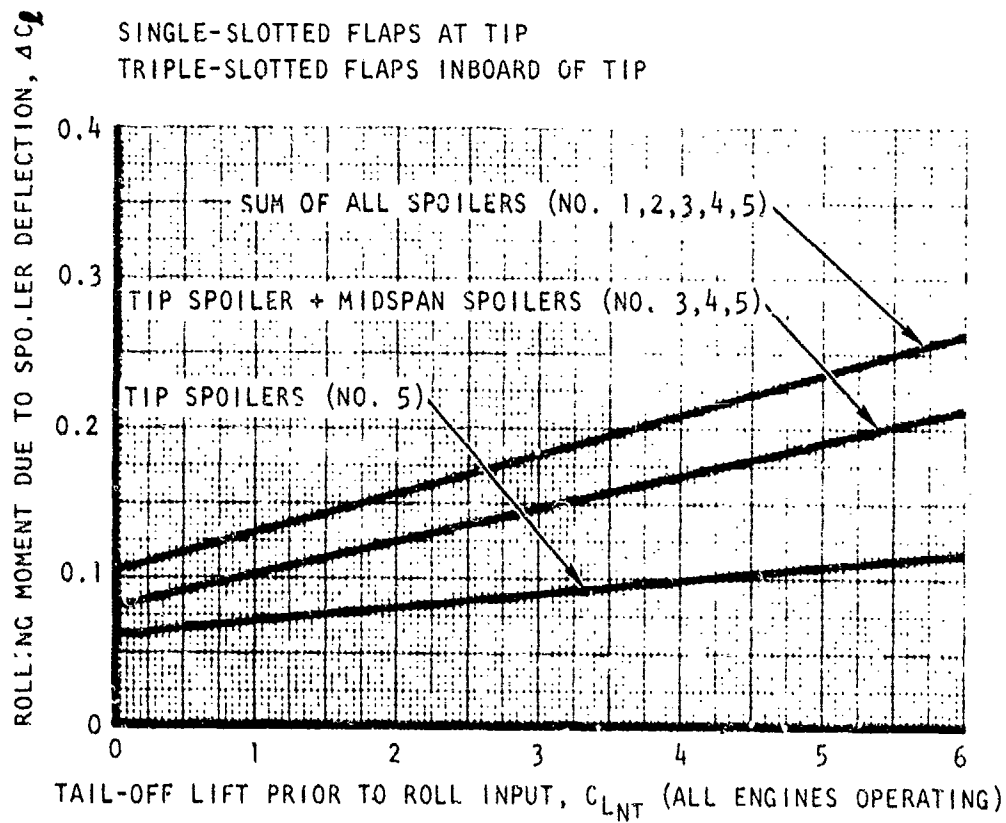Figure 54. Available Roll Control From Spoilers Versus Tail-Off Lift

75

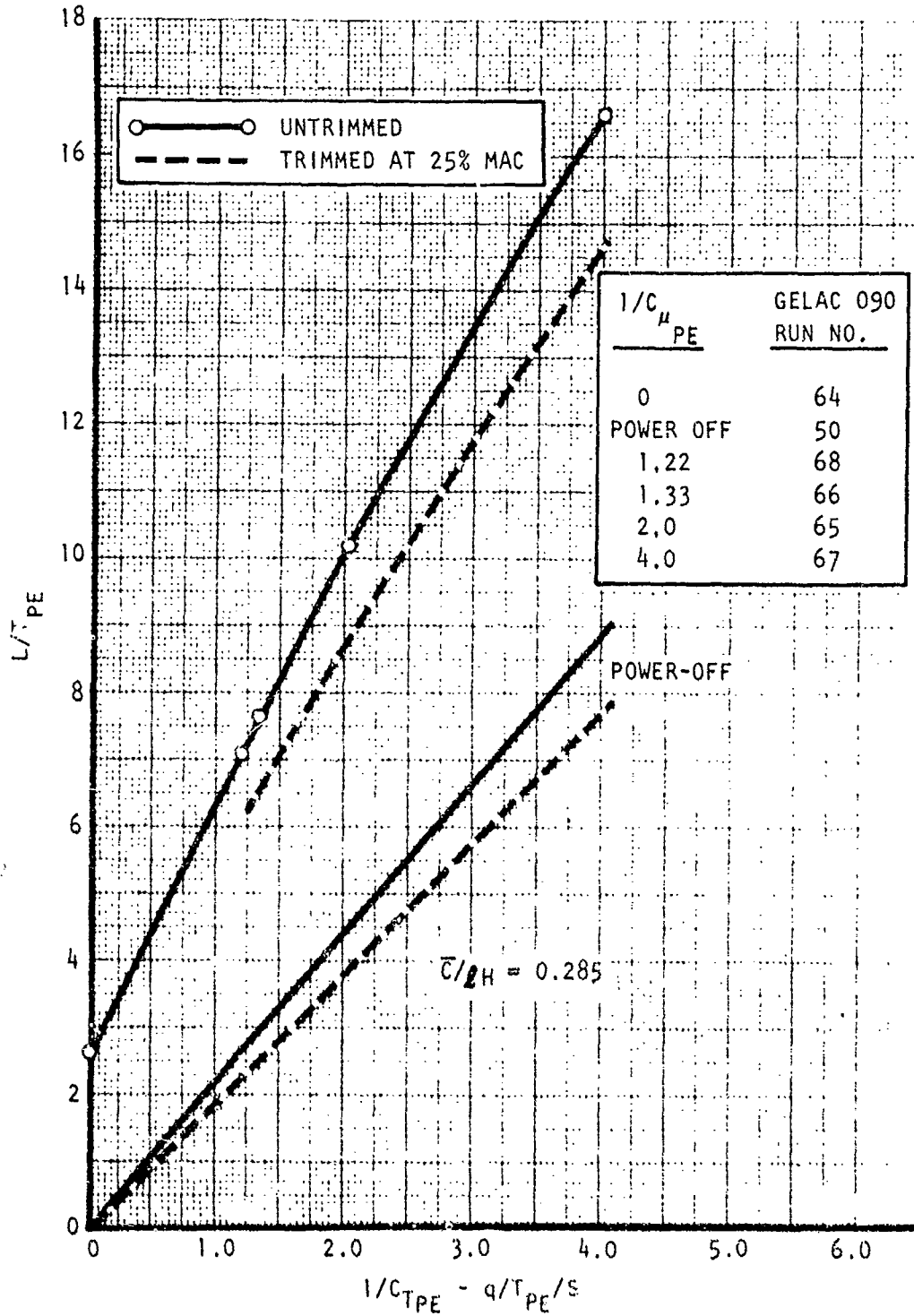Figure 55. Available Roll Control From Spoilers Versus Tail-Off Lift
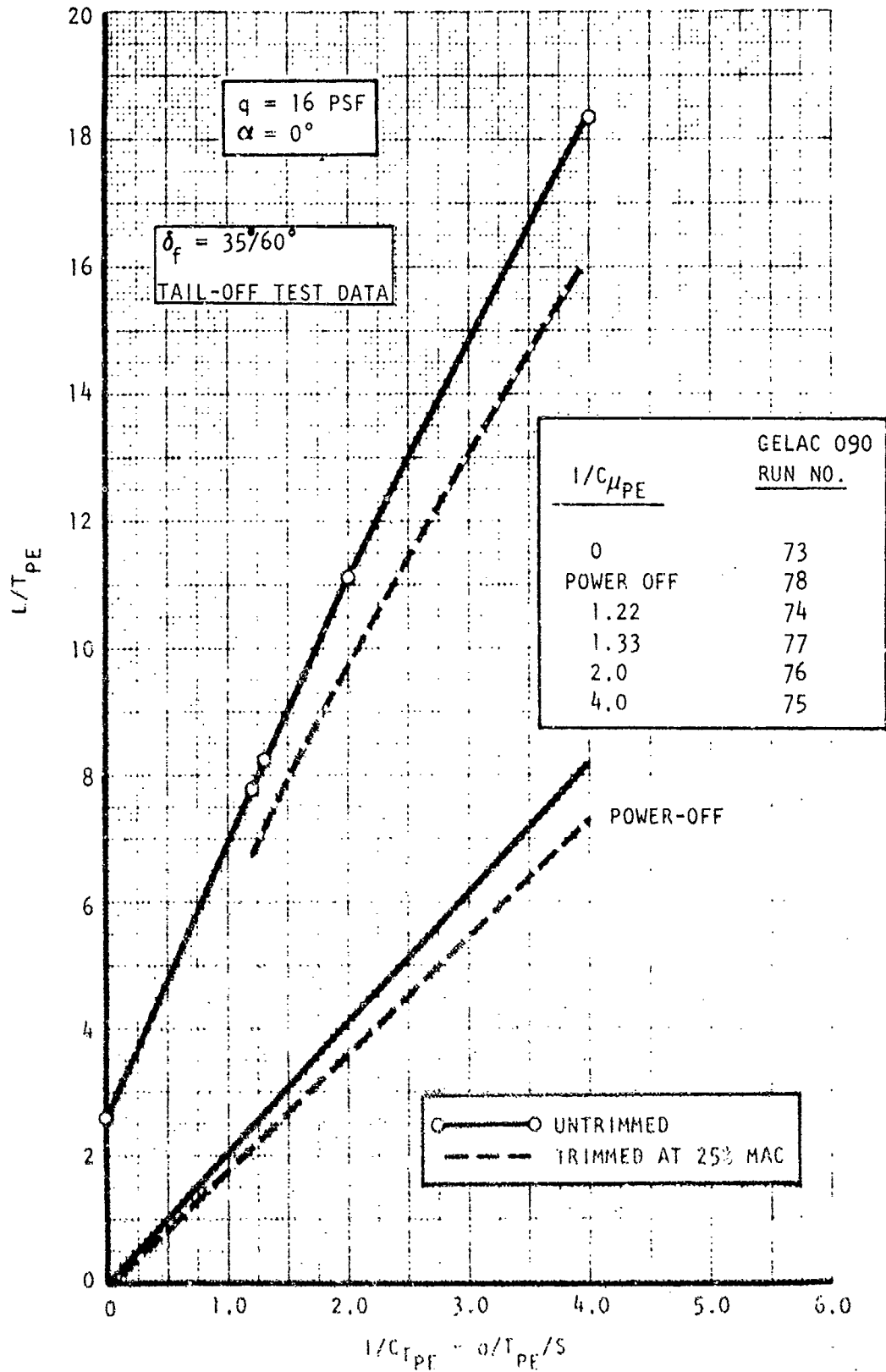
Figure 56. Double-Slotted Flap Lift Characteristics

77

Figure 57. Double Slotted Flap Lift Characteristics

FOUR ENGINE OPERATION
DOUBLE-SLOTTED FLAPS

$\delta_F = 25°/50°$
$\delta_{SP} = -10°/50°$
TAIL ON
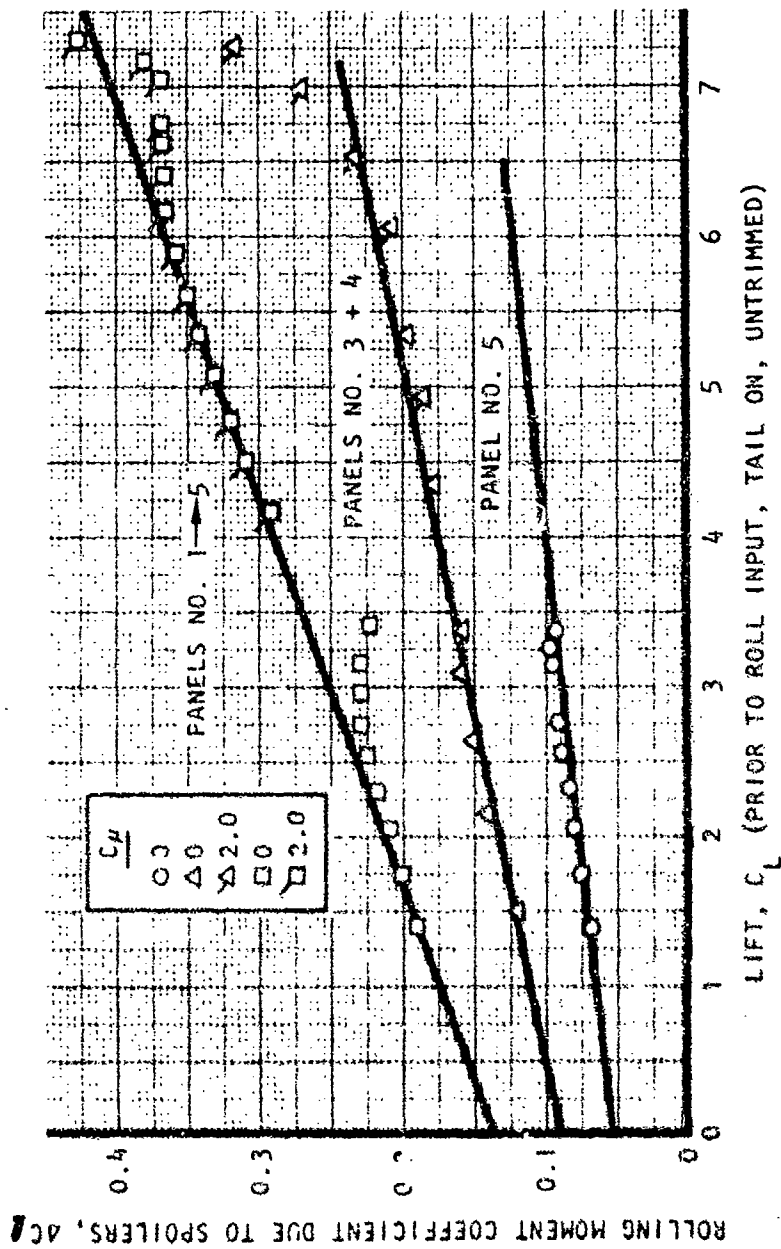
Figure 58. Effect of Spoilers on Rolling Moment

DOUBLE-SLOTTED FLAPS

$\delta_F = 25°/50°$
$\delta_{SP} = -10°/50°$

TAIL ON

$C\mu$
O 0
O 2.5
△ 0
△ 2.5

PANELS NO. 3+4+5

PANEL NO. 5
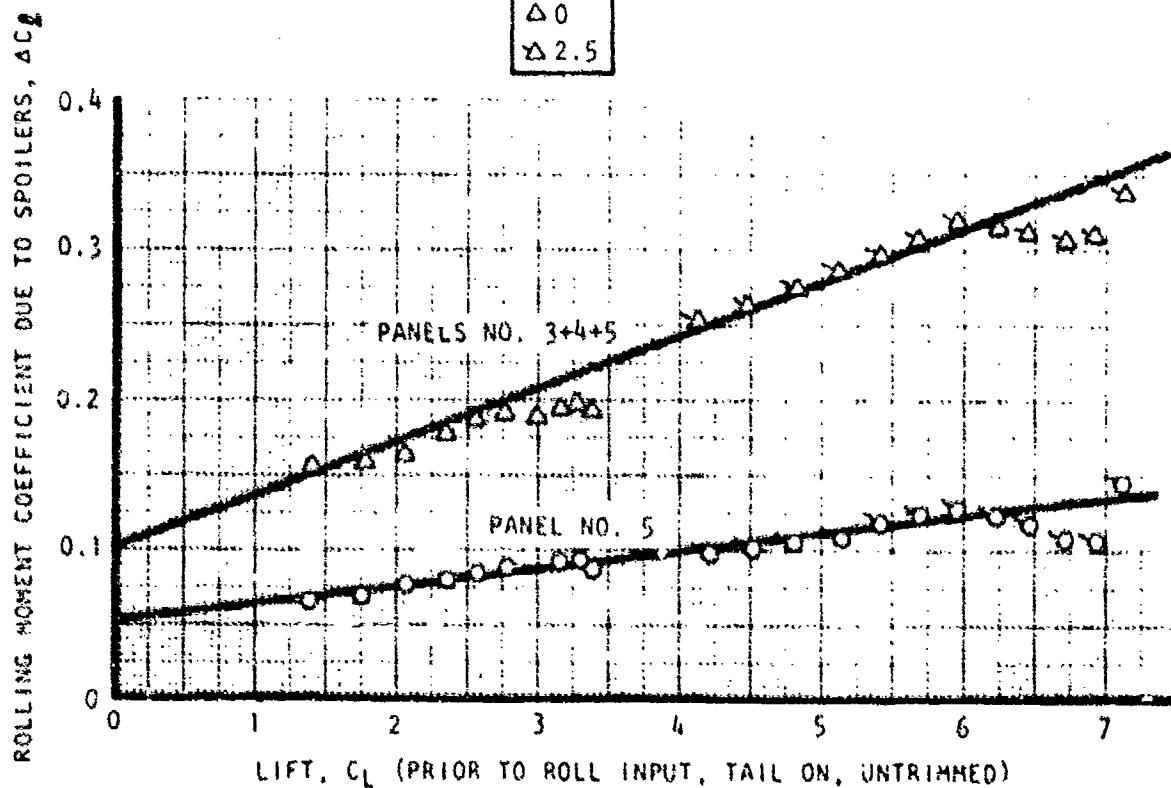
Figure 59. Effect of Spoilers on Rolling Moment, Three Engine Operation

Figure 60. Rolling Moment Coefficient Due to Spoiler and Aileron Deflection

$$\delta_F = 25°/50°$$

$$\frac{q}{T_{PE}/S} = 2.0 \ (AEO)$$

$$i_H = 0°$$

Figure 61. Tail Effect on Total Lift

4.2.2 AILERONS WITH BLC

Assuming an average (neutral) deflection of 50 degrees of the surfaces at the tip, then asymmetric blowing of the surface with a total $C_{\mu \, AIL}$ = .065 is estimated to give a rolling moment coefficient of .054. This estimate is based on Figure 62 which is obtained from wind tunnel tests (GELAC 090).
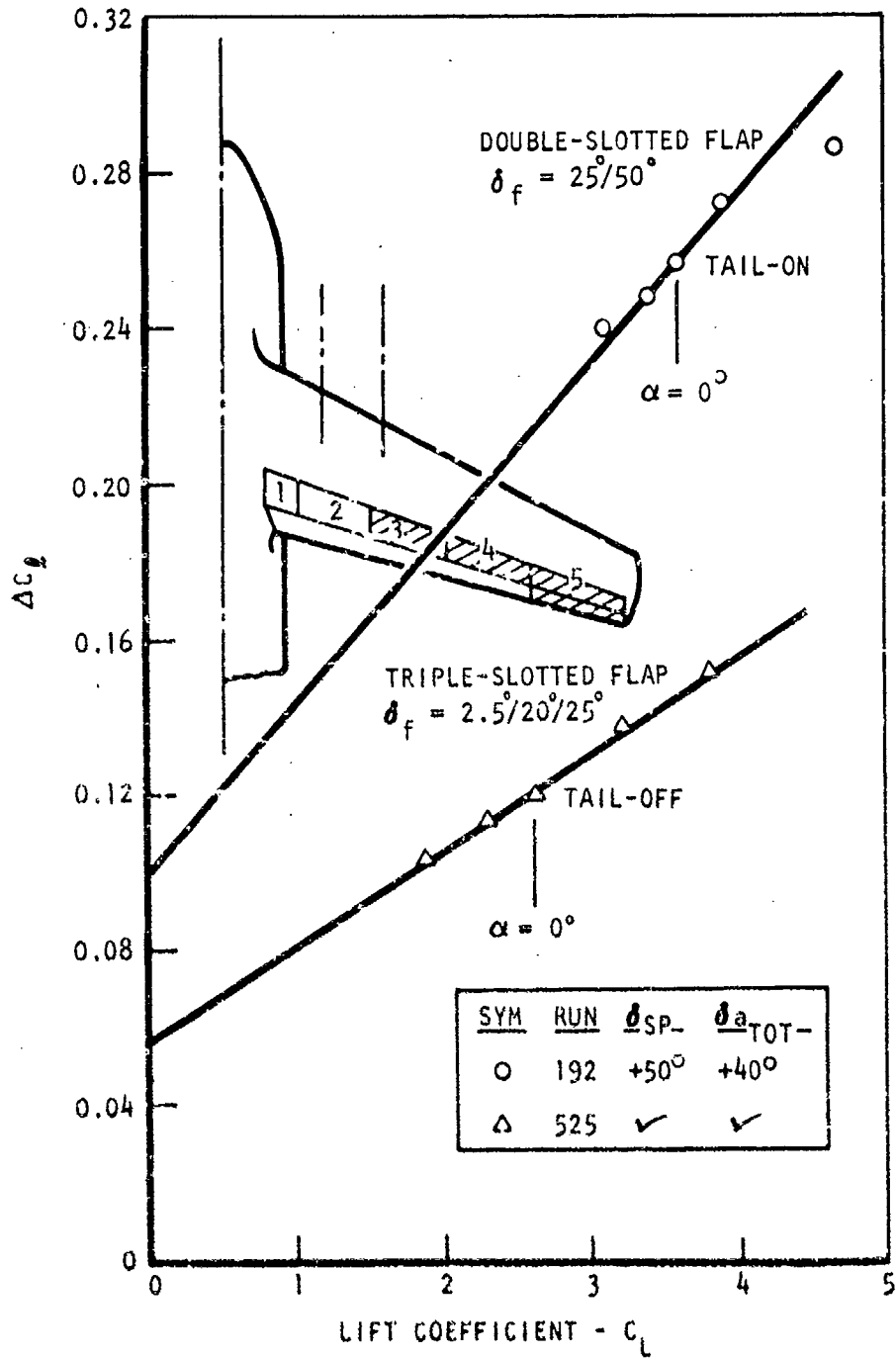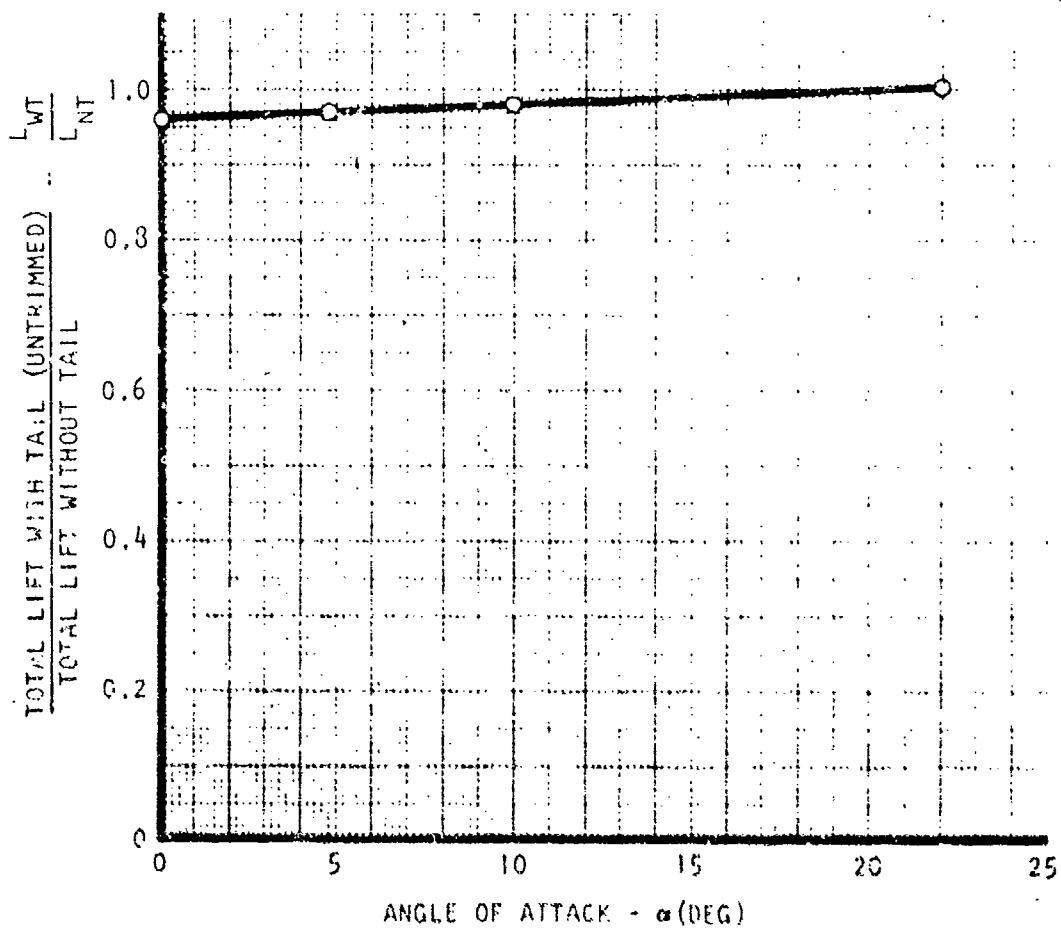
A differential surface deflection is applied, such that the deflection at the one side, with BLC, is 70 degrees and at the other, without BLC, is 30 degrees. It is estimated that the rolling moment due to asymmetric BLC for the higher flap angle is increased by 15 percent to C_ℓ = .063. The rolling moment coefficient of the differential aileron surface without blowing is about C_ℓ = .010 which is to be added. The total rolling moment from ailerons and BLC thus becomes C_ℓ = .073.

If the neutral surface deflection is 30 degrees instead of 50 degrees, 80 percent of this rolling moment is used.

$\delta_A = 35°/50°$
(EQUAL DEFLECTION
ON BOTH WING PANELS)

TAIL ON
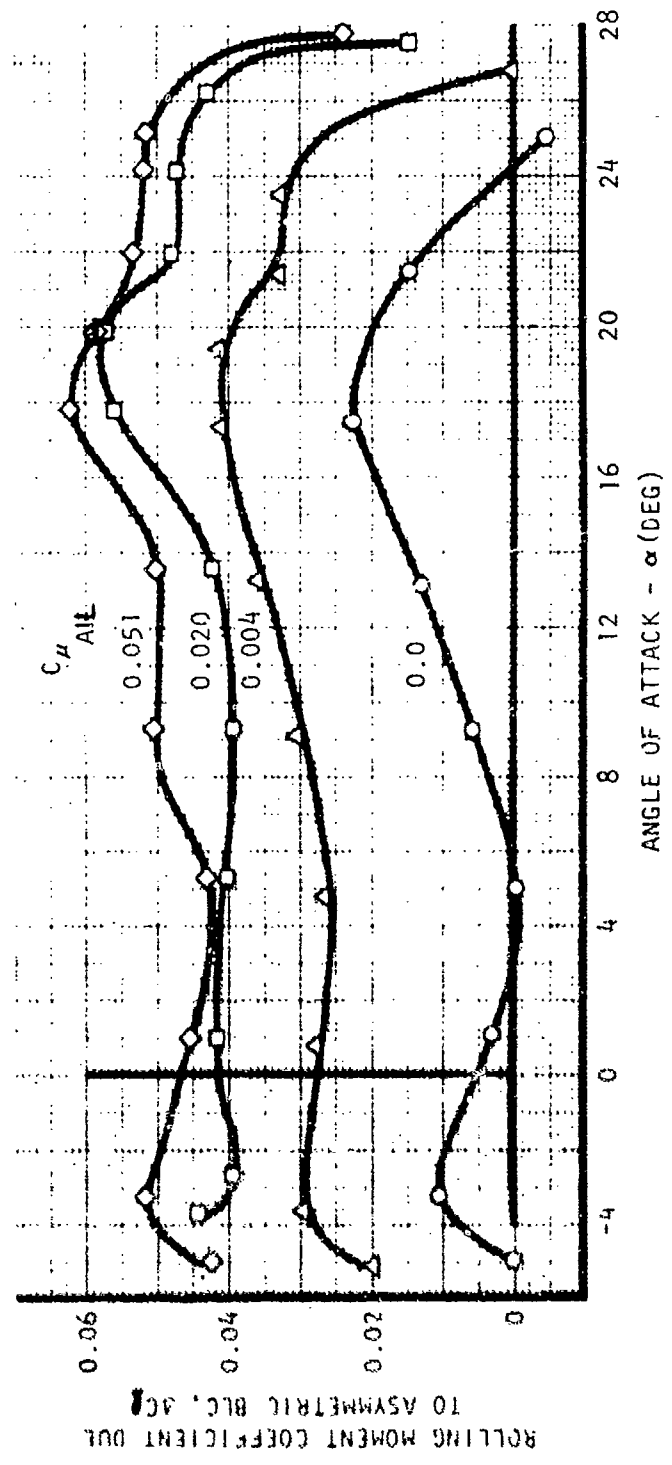
ASYMMETRIC
AILERON
BLOWING

Figure 62. Rolling Moment Due to Blow Aileron Asymmetric BLC

84

Section V

COMPARISON OF ROLL ACCELERATION
WITH ONE ENGINE INOPERATIVE

5.1 REQUIRED AND AVAILABLE ROLLING MOMENTS

According to MIL-F-83300 the roll control must be adequate to reach a bank angle of 30 degrees in 3.6 seconds for Level 3 (critical engine failed).

Using a control system lag of 0.1 second, a full roll control in 0.4 second after pilot control initiation, and $\tau_R = 0.7$, the above requirement can be written as:

$$\frac{\mathcal{L}}{I_{xx}} = \ddot{\phi}_o = .23 \text{ rad/sec}^2$$

or

$$\frac{C_\ell}{C_L} = \frac{\ddot{\phi}_o}{\left(\frac{W \cdot b}{I}\right) n} \approx \frac{0.0195}{n}$$

where n = normal acceleration, and C_L is the trimmed lift coefficient.

This rolling moment requirement is to be added to the rolling moment needed to overcome the engine failure. The magnitude of it is described as follows.

The failure moment depends on the lift generated by power effects. At low lift coefficients power effects are not needed to support the aircraft and the rolling moment coefficient due to engine failure, $\Delta C_{\ell_{EF}}$, may then be zero. This is illustrated in Figure 63 by the line OA. If a higher lift coefficient is flown, and α is given (for example zero) then power effects are used and a finite $\Delta C_{\ell_{EF}}$ exists as sketched in the figure by line AB. The C_L value of point B represents the lift that can be generated at $\alpha = 0$, depending on the blowing coefficient $1/C_{\mu_{PE}} = q/(T_{PE}/S)$. A similar line exists for the maximum angle of attack which is illustrated by line CD. The envelope OABD represents the maximum rolling moment coefficient for a given blowing coefficient and provided $\alpha = 0$ is the minimum angle considered.
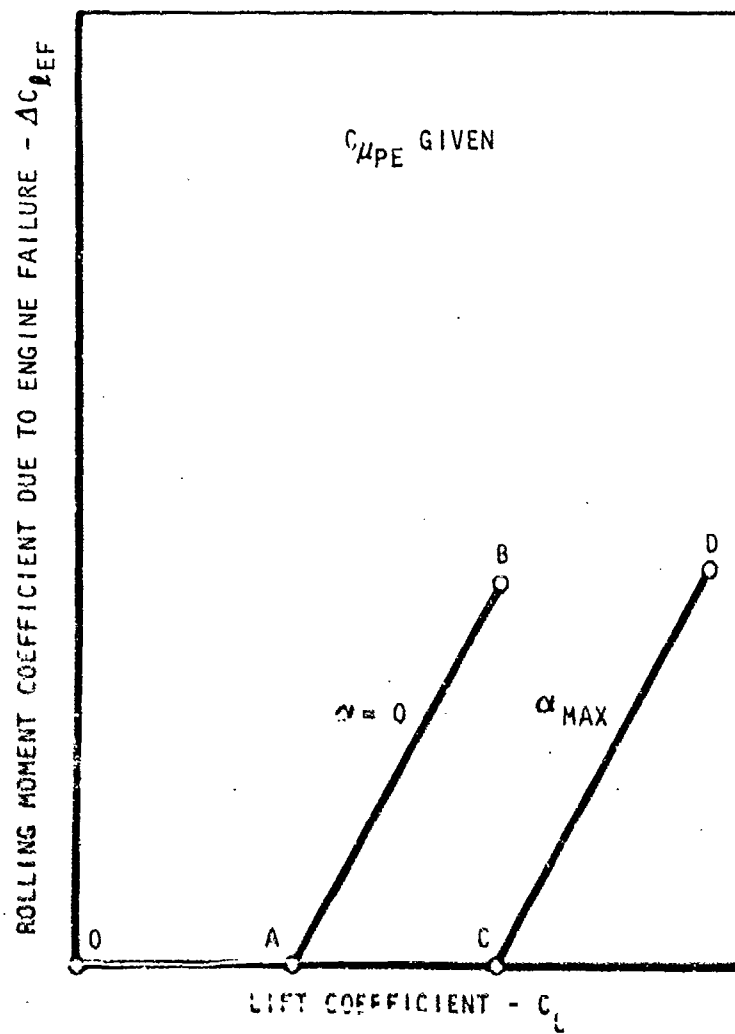
Figure 63. Rolling Moment Due to Engine Failure, Schematic Variation With C_L

86

Adding the above discussed moment to provide the roll acceleration yields the envelope OA'B'D' shown in Figure 64. Herein n = 1 is used as the critical case.

Plots such as these are given in Figures 65 through 68 for the various configurations considered, using the relation of $\Delta C_{\ell\,EF}$ with C_{Lp} as given in Figure 38, and using high flap angles because these are critical. Rolling moment due to rudder for yawing moment equilibrium is not used here because for large flap angles this effect would subtract rather than add. Flap angles of 70 degrees for the double slotted and 65 degrees for the triple slotted flaps are chosen, which are arbitrarily high except these two flap angles provide comparable lift with re .ect to each other. The maximum angle of attack used is 18 degrees, being the stall angle of attack in case an engine fails. The lift values used are:

FLAP	$\propto$	C_L		
		POWER OFF	$q/(T_{PE}/S)=2.0$	$q/(T_{PE}/S)=1.21$
Double slotted, 70°	0	2.23	6.08	7.00
	18	3.13	7.69	8.91
Triple slotted, 65°	0	2.09	5.78	8.64
	18	3.67	7.80	9.17

The required rolling moment coefficients are compared in these figures with the available rolling moments. These are the same as those presented in a previous section.

It is seen that the roll acceleration requirement is met for the double slotted flap with or without BLC at the ailerons at all speeds above the critical engine-out stall speed. Also for partial span triple slotted flaps, where full span spoilers and aileron BLC is used, the requirement is met at all speeds, but not for full span triple slotted flaps without BLC. However, in any case, also without BLC, the speeds are lower than those where the Level 1 roll acceleration is met with all engines operating, compare Figure 69 with 52. Thus in any event, the roll acceleration in normal operation is more critical than the roll acceleration with one engine out.
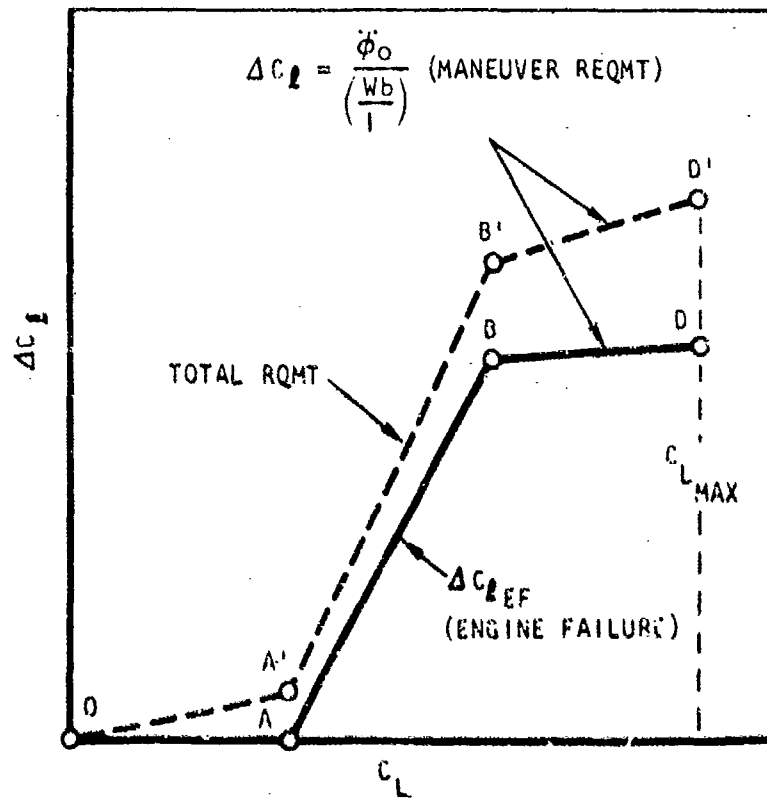
87

$$\Delta C_{\ell} = \frac{\ddot{\phi}_0}{\left(\frac{Wb}{I}\right)} \quad \text{(MANEUVER REQMT)}$$

TOTAL RQMT

$\Delta C_{\ell_{EF}}$ (ENGINE FAILURE)

$C_{L_{MAX}}$

C_L

ΔC_{ℓ}

Figure 64. Schematic Variation of Required Roll Control to Meet Roll Acceleration After Engine Failure

$$\delta_F = 70°$$
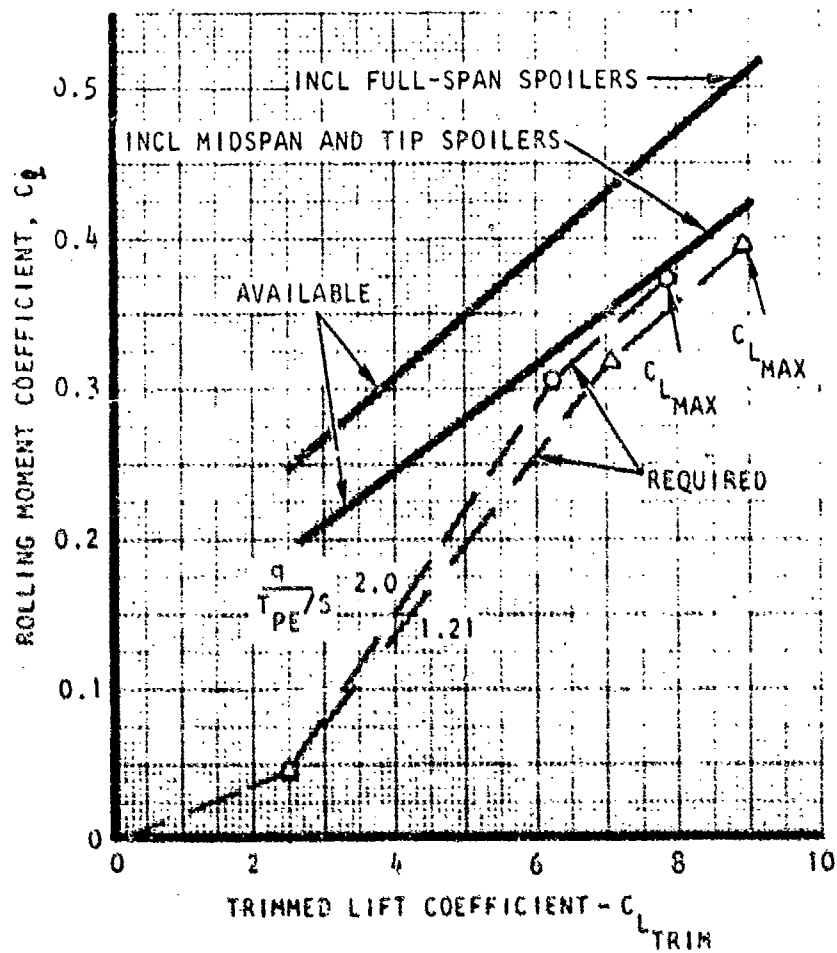
FULL-SPAN, DOUBLE-SLOTTED FLAPS
AILERONS WITHOUT BLC

Figure 65. Required and Available Roll Control After Engine Failure

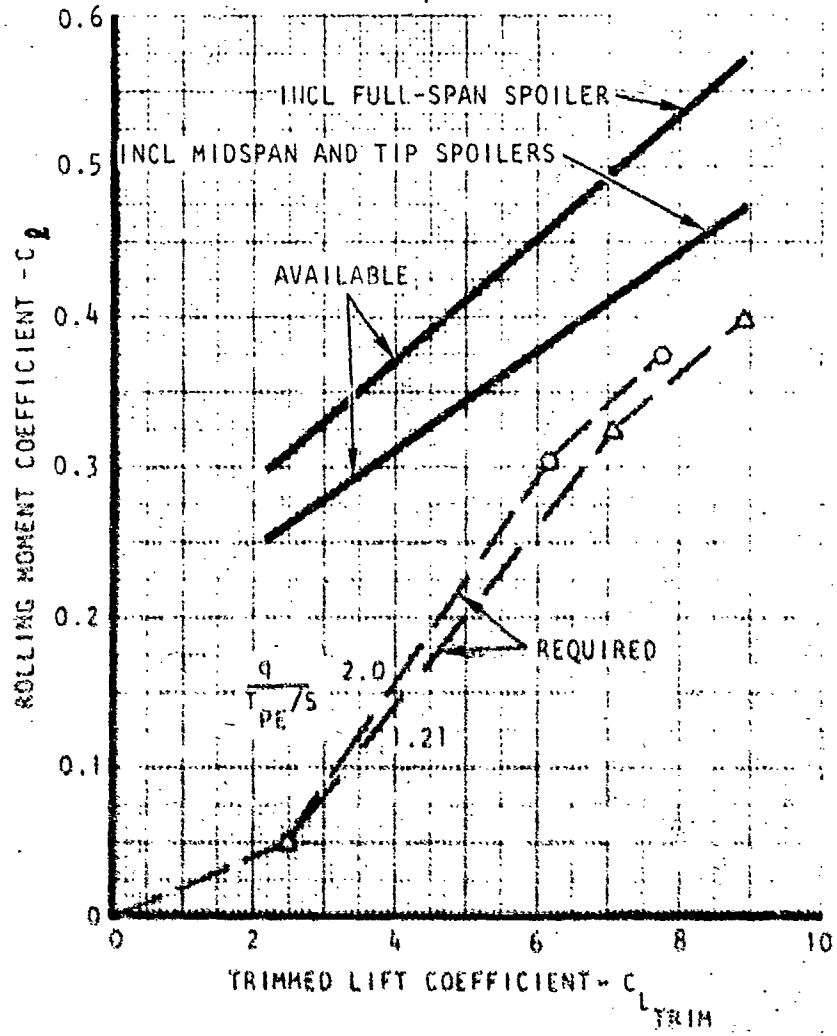INBOARD DOUBLE-SLOTTED FLAPS
AILERONS WITH BLC
$\delta_F = 70°$

Figure 66. Required and Available Roll Control After Engine Failure

90

$$\delta_F = 65°$$
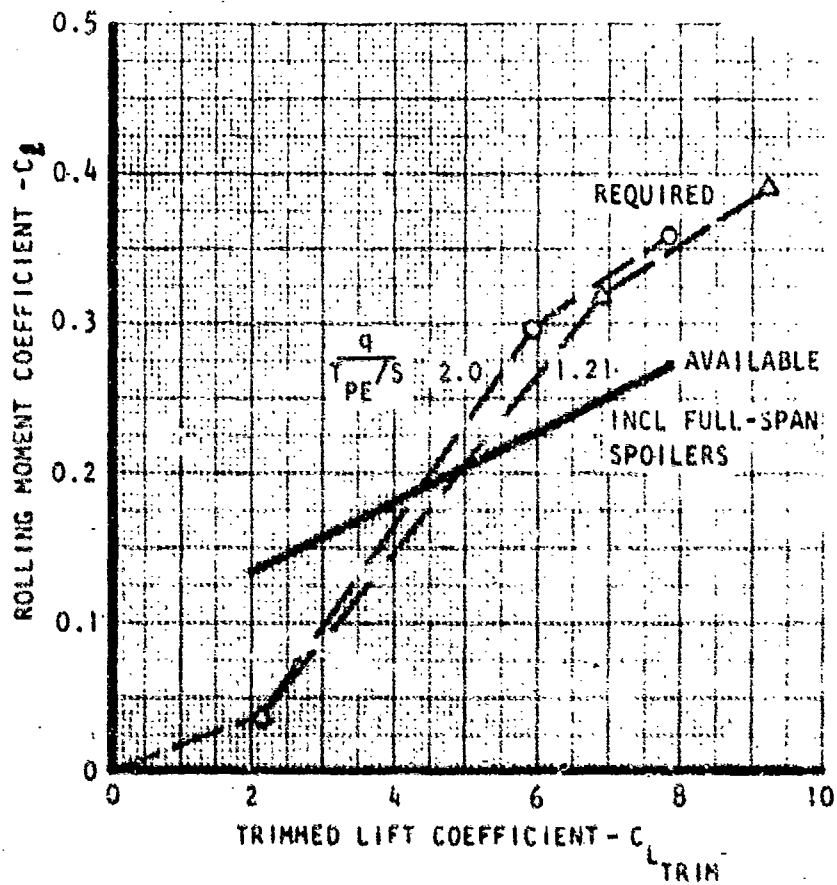
FULL-SPAN TRIPLE-SLOTTED FLAPS
AILERONS WITHOUT BLC

Figure 67. Required and Available Roll Control After Engine Failure

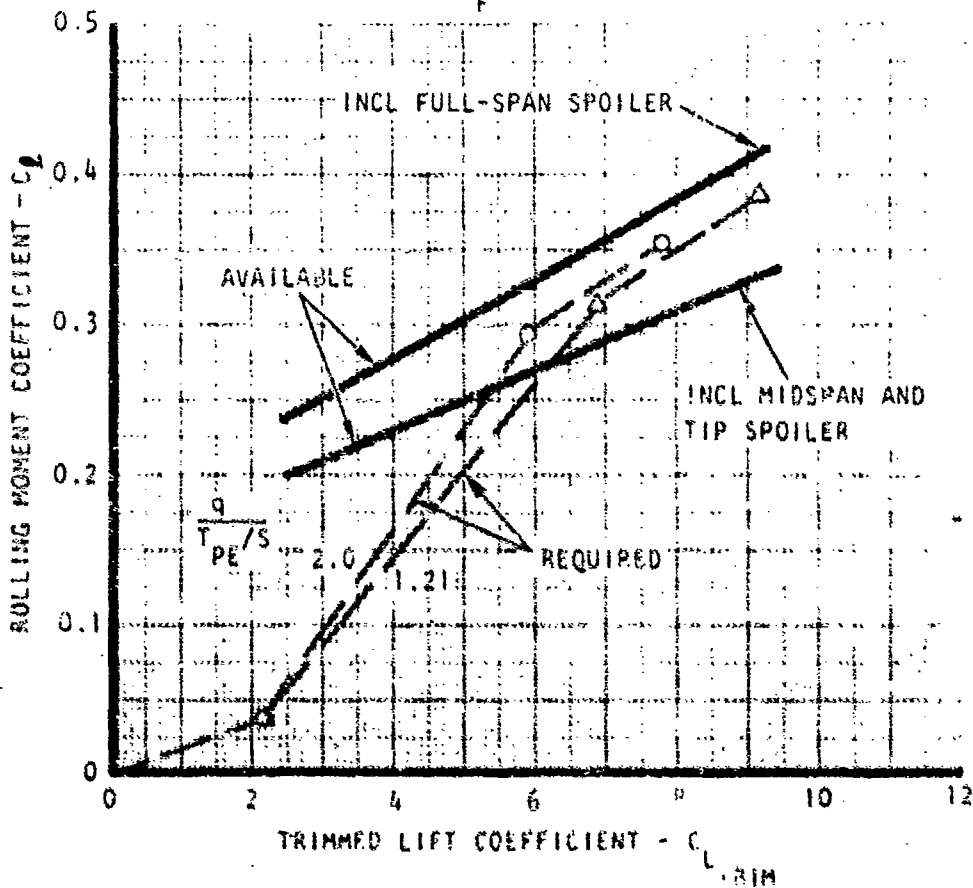INBOARD TRIPLE SLOTTED FLAPS
AILERONS WITH BLC

$\delta_F = 65°$

Figure 66. Required and Available Roll Control After Engine Failure

LEVEL 3
(OUTBD ENGINE INOPERATIVE)

$\delta_F = 65^O$ TO 70°, $q/(T_{PE}/S) = 2.0$

☐ SPOILERS ONLY AT MIDSPAN AND AT TIP
▨ SPOILERS FULL SPAN

V_S INBD DOUBLE-SLOTTED FLAPS
V_S AND AILERONS WITH BLC

V_S FULL-SPAN, DOUBLE-
V_S SLOTTED FLAPS

INBD TRIPLE-SLOTTED FLAPS
V_S AND AILERONS WITH BLC

FULL-SPAN TRIPLE SLOTTED
FLAPS

0   20   40   60   80   100
EQUIVALENT AIRSPEED - V (KEAS)
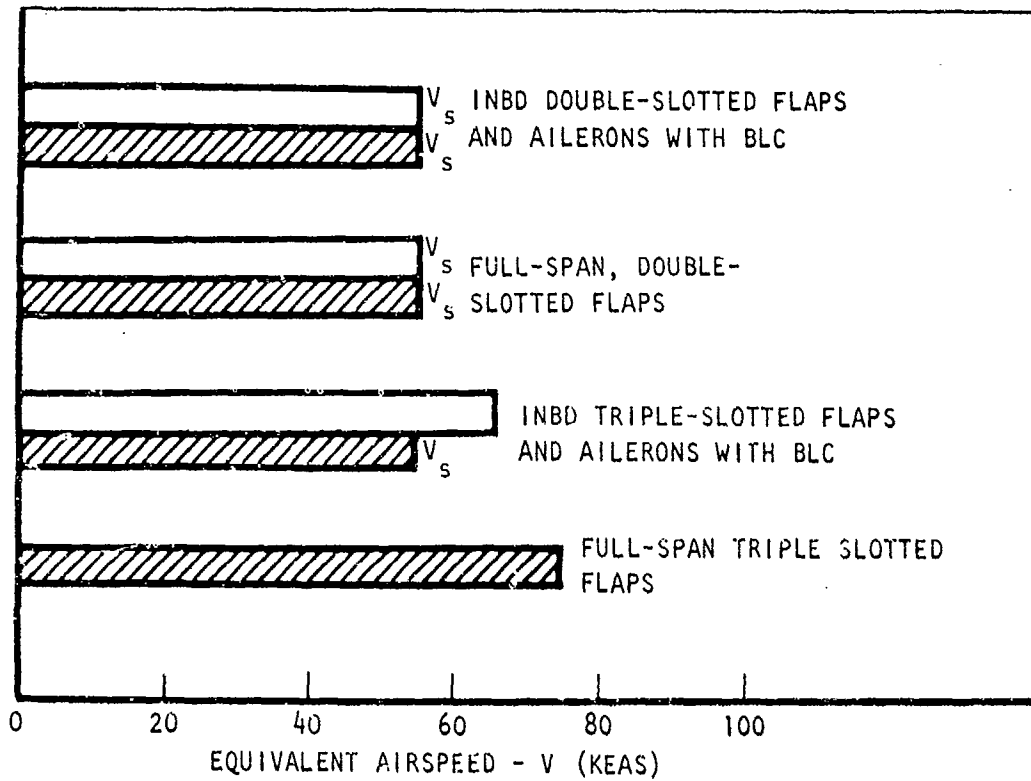
Figure 69. Comparison of Speeds at Which Required Roll Acceleration is Met

93

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Section VI

COMPARISON OF LIFT LOSS
DUE TO MAXIMUM ROLL CONTROL

The lift loss due to roll control belonging to certain roll accelera-
tion capabilities is shown for the various configurations in Figures 70
through 73. The curves do not include ground effect. They are obtained
from data of $\Delta C_L/C_L$ versus C_ℓ given previously in Figures 43 through
45, and using

$$\frac{\ddot{\ell}}{I} = \frac{C_\ell \cdot \bar{q}}{W/S} \cdot \left(\frac{Wb}{I}\right) = \frac{C_\ell \cdot \bar{q}}{80} \quad (11.9)$$

Adding ground effect from Figure 74 results in lift losses shown
in Figure 75. It is seen that these lift losses can be extremely large.

During landing, these lift losses cannot be tolerated unless they are
largely compensated by direct lift control (DLC). DLC is used to over-
come the sudden lift loss due to engine failure, to compensate for ground
effect, and to nullify most of the lift loss due to roll control by an
interconnect system.

Figure 76 shows the required normal acceleration of the DLC system to
compensate most of the lift loss for the various geometries under considera-
tion. The required values increase with lower flight speed because the
lift loss due to ground effect is larger with higher values of C_L. Not
all lift loss is compensated; a remainder of $\Delta C_L/C_L = .125$ is left
when the maximum required roll control capability of $\ddot{\phi}_o = .825$ is applied
in ground effect with all engines operating. If this maximum roll
control is maintained for one second (in ground effect) the remaining
lift loss results in an increase of the sink velocity of approximately
4 ft/second.

The available normal acceleration is also indicated in that figure.
The magnitude is computed from closing a full span spoiler with as much
lift variation on both wing panels together as that associated with a
maximum roll control input with full span spoilers on one wing panel only,
see Figure 77. The lift loss due to the opening of roll control spoilers
is therefore taken to indicate the amount of DLC available. These lift
losses are then converted into a Δn availability that is shown in figure
78.

The speeds where the required and available normal acceleration capa-
bility are equal are read from Figure 76 and presented separately in a
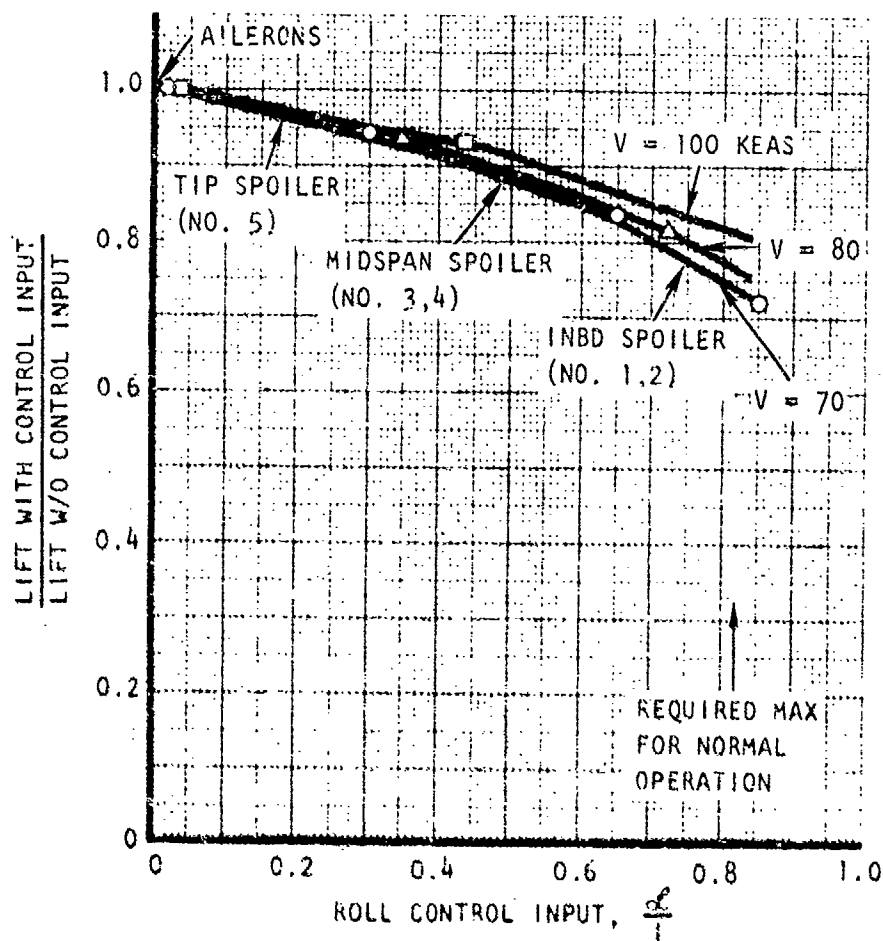bar chart in Figure 79.

95

Figure 70. Lift Loss Due to Roll Control Without Ground Effect

96

W/S = 80

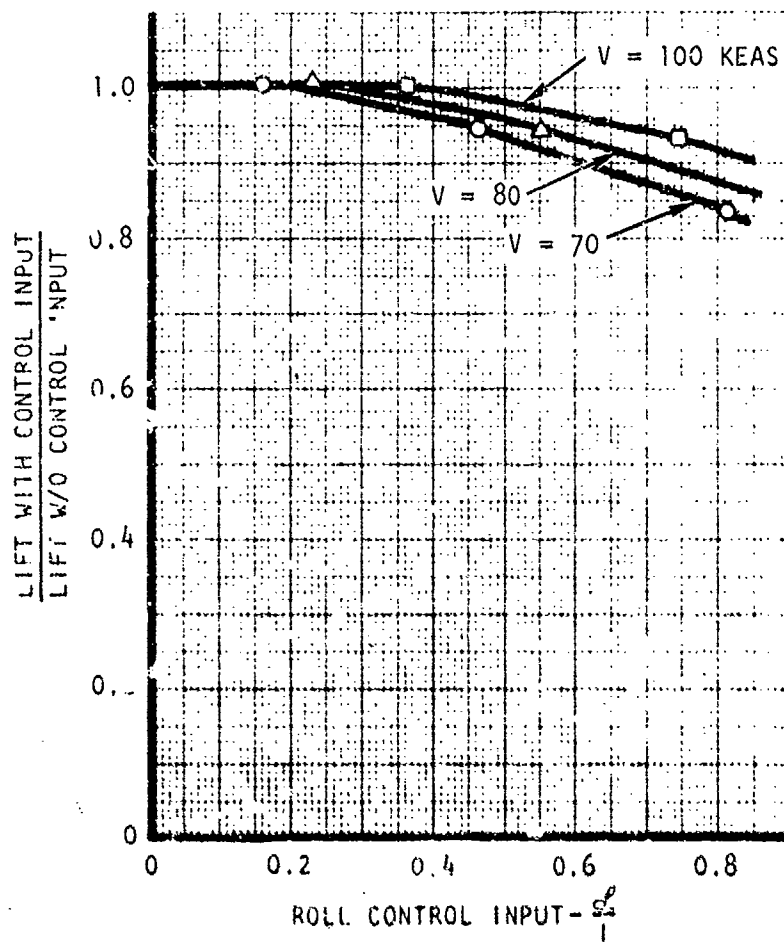DOUBLE-SLOTTED FLAPS WITH AILERON BLC

Figure 71. Lift Loss Due to Roll Control Without Ground Effect

97

W/S = 80

TRIPLE-SLOTTED FLAPS WITHOUT AILERON BLC
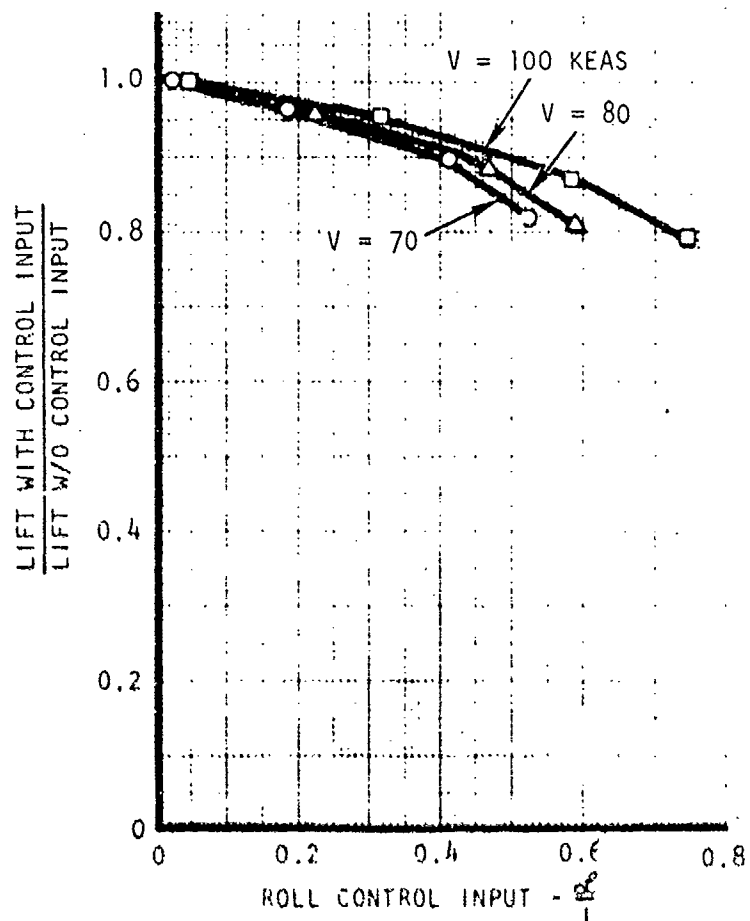

Figure 72. Lift Loss Due to Roll Control Without Ground Effect
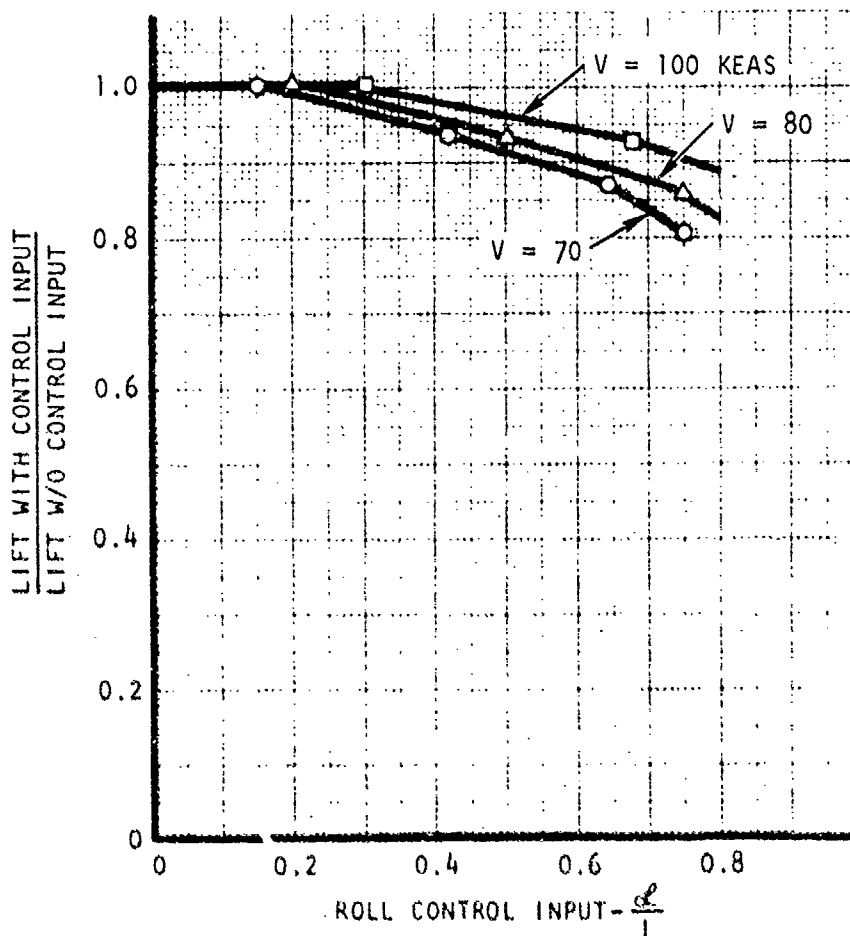
W/S = 80

TRIPLE-SLOTTED FLAPS WITHOUT AILERON BLC

Figure73. Lift Loss Due to Roll Control Without Ground Effect

99

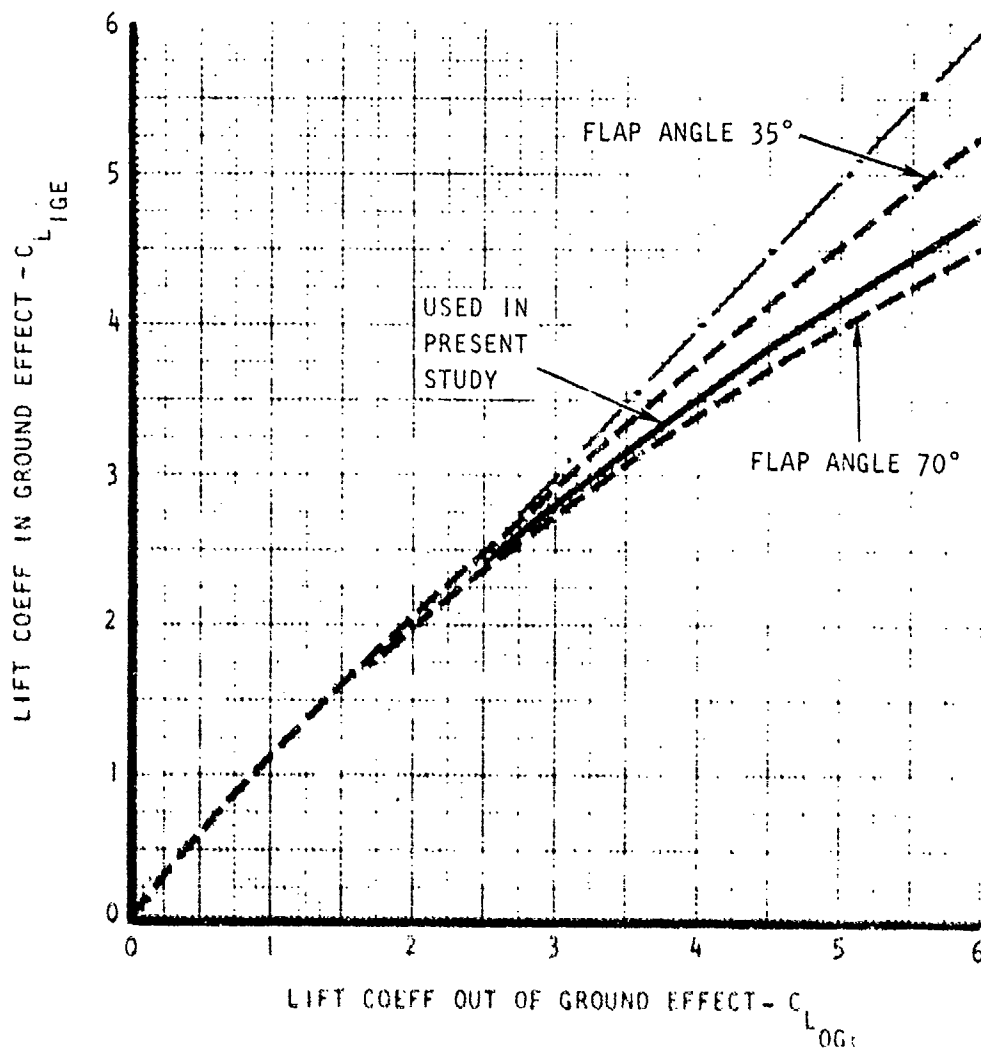MAX EFFECT (WHEELS ON GROUND) TAIL OFF

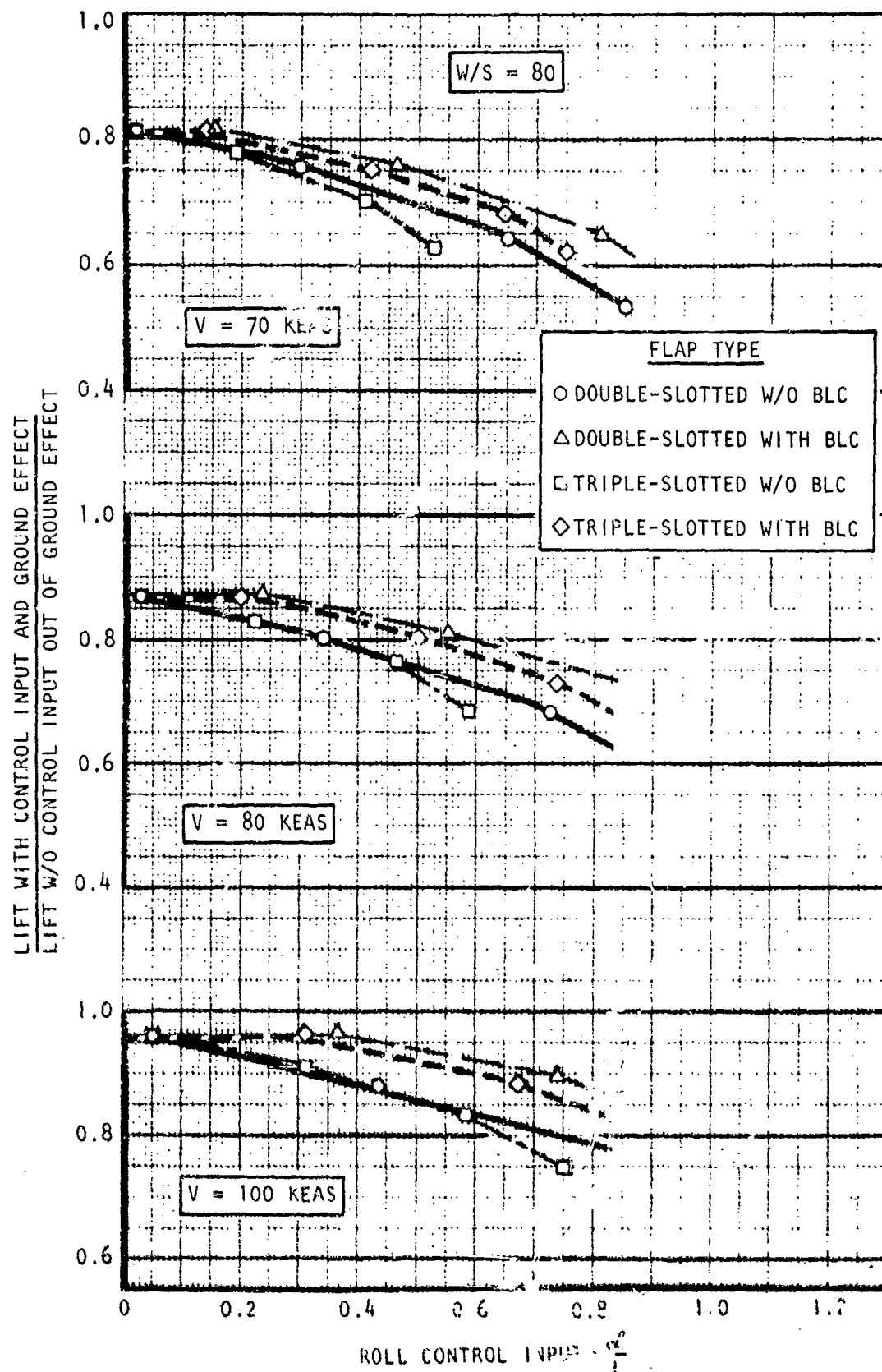Figure 74. Ground Effect on Tail-Off Lift At Angles of Attack Below Stall

100

Figure 73. Lift Loss Due to Roll Control With Ground Effect

101

W/S = 80
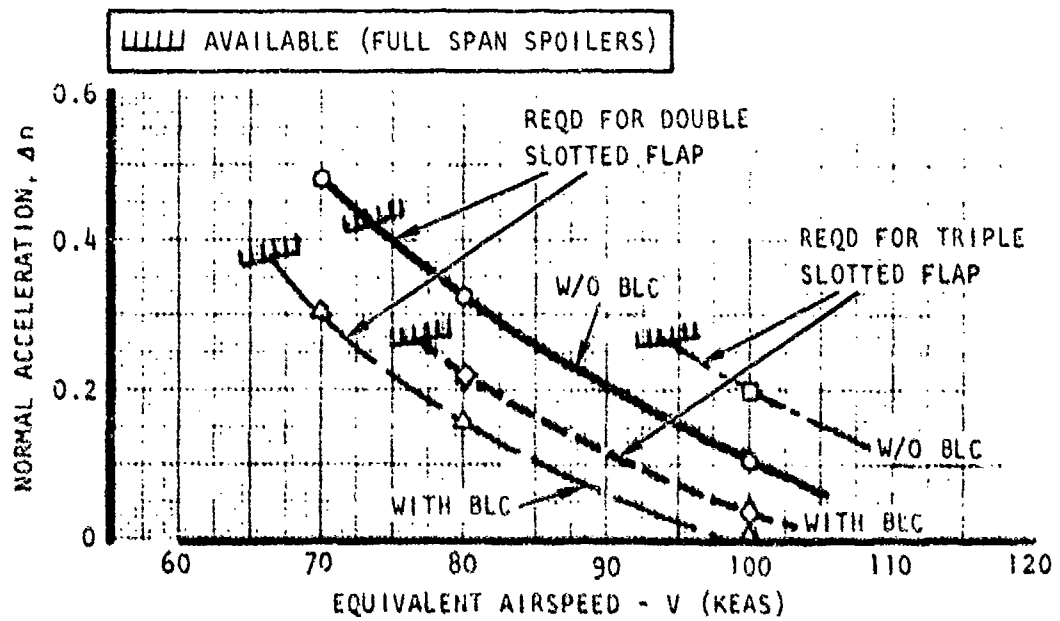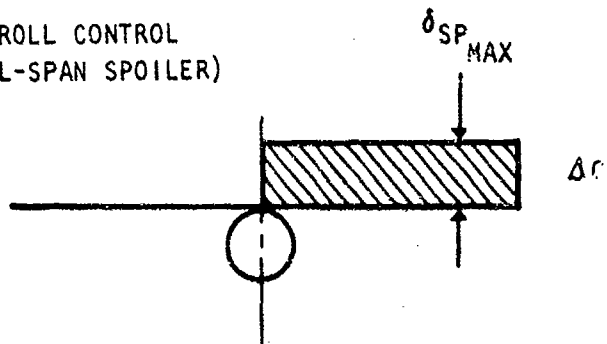
Figure 76. Required and Available Δn With Direct Lift Control

1. MAX ROLL CONTROL
   (FULL-SPAN SPOILER)

$\delta_{SP_{MAX}}$

Δc

2. MAX DLC

$1/2\ \delta_{SP_{MAX}}$

Δc_{L_2}
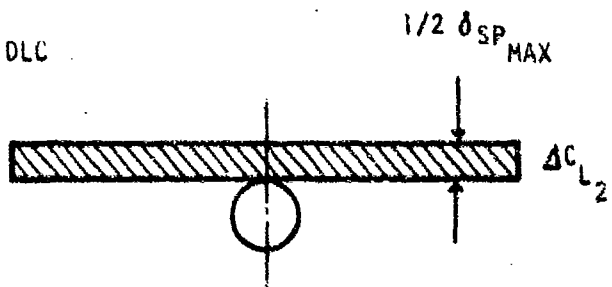
$$\Delta c_{L_1} = \Delta c_{L_2} \quad \text{(BASED ON TOTAL WING AREA)}$$

Figure 77. Determination of Maximum Available DLC

103
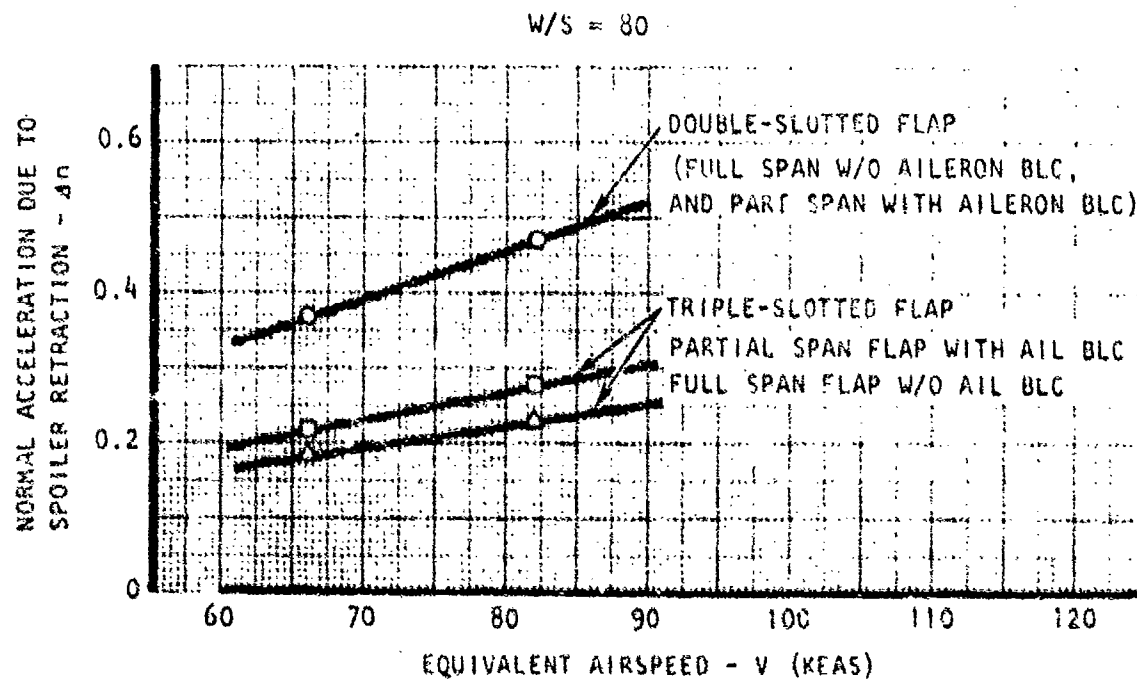
Figure78. Available DLC with Full-Span Spoilers

104

W/S = 80
ALL ENGINES
OPERATING

INBD DOUBLE-SLOTTED FLAPS
AND AILERONS WITH BLC

FULL-SPAN DOUBLE-
SLOTTED FLAPS

INBD TRIPLE-SLOTTED FLAPS
AND AILERONS WITH BLC

FULL SPAN TRIPLE-SLOTTED
FLAPS

0   20   40   60   80   100

EQUIVALENT AIRSPEEDS - V (KEAS)

Figure 79. Comparison of Speeds Where Maximum Available DLC is Adequate

Section VII

CONCLUSIONS AND RECOMMENDATIONS

This report provides aerodynamic data to make a design choice between double and triple slotted flaps and between a roll control system with BLC or without BLC for the baseline configuration definition in Volume I. The study in this report is based on a comparison of minimum speeds at which safety, stability and control, and performance criteria are met.
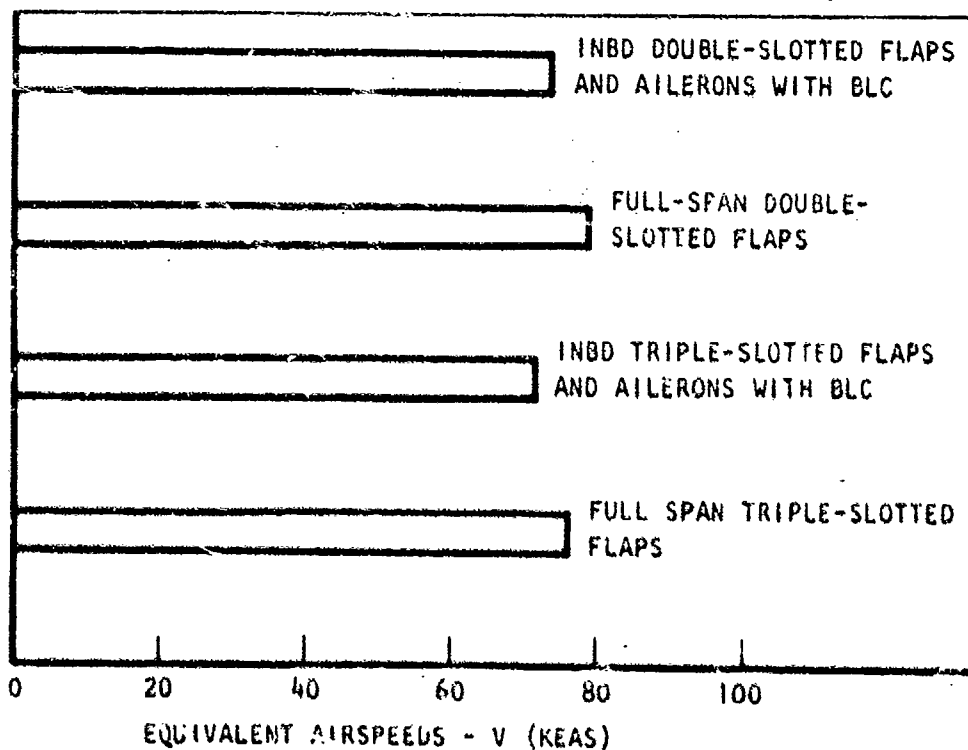
The minimum speeds are, using arbitrary values of $W/S = 80$ and $T/W = 0.55$ for comparison purposes:

1. Full span double slotted flaps, without BLC: 79 knots
2. Inboard double slotted flaps, outboard BLC: 74 knots
3. Full span triple slotted flaps, without BLC: 107 knots
4. Inboard triple slotted flaps, outboard BLC: 77 knots

The minimum speed for triple slotted flaps is limited by the relatively smaller roll control capability and is at best 3 knots higher than the minimum speed for double slotted flaps. Using BLC can reduce the minimum speed for double slotted flaps by approximately 5 knots for the same engine exhaust thrust. If the engine thrust is reduced because of bleed air extraction the benefit of BLC becomes less, and its application becomes questionable.

It should be noted that if the roll control power for the triple slotted flap is somewhat larger than estimated, or if the flow through a flap gap of the triple slotted flap can be manipulated together with the roll control spoiler actuation, the speed for this flap configuration may be less. In this connection it should be noted that the above conclusions are based on somewhat inadequate data for the roll control spoiler effectiveness for triple slotted flaps. Data of only one test run of this effectiveness is available and some reservation of pertinent conclusions should be made until the roll control effectiveness is confirmed by additional wind tunnel test data. It is strongly recommended that these should be obtained.

REFERENCES

1. Mil-F-83300, "Military Specification - Flying Qualities of Piloted V/STOL Aircraft", USAF, AFFDL, Wright Patterson AFB, dated 31 December 1970

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3. AGARD Report 408A, "Recommendations for V/STOL Handling Qualities with an Addendum Containing Comments on the Recommendations", North Atlantic Treaty Organization, Advisory Group for Aeronautics Research and Development, Flight Mechanics Panel Working Group, dated July 1963

4. LSWT 090, "Test of a 0.0718. Scale Model of the NR Research STOL Transport in the Lockheed/Georgia Company Low Speed Wind Tunnel", dated July 1972

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