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STOL TACTICAL AIRCRAFT INVESTIGATION. VOLUME III. TAKEOFF AND LANDING PERFORMANCE GROUND RULES FOR POWERED LIFT STOL TRANSPORT AIRCRAFT

Franklyn J. Davenport, et al

Boeing Aerospace Company

Prepared for:

Air Force Flight Dynamic Laboratories

May 1973

AFFDL-TR-73-19
Volume III

STOL TACTICAL AIRCRAFT INVESTIGATION

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Takeoff and Landing Performance Ground Rules for Powered Lift STOL Transport Aircraft

Franklyn J. Davenport
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Vernon F. Van Heyningen

THE BOEING COMPANY

Technical Report AFFDL-TR-73-19 – Volume III

May, 1973

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Air Force Flight Dynamics Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

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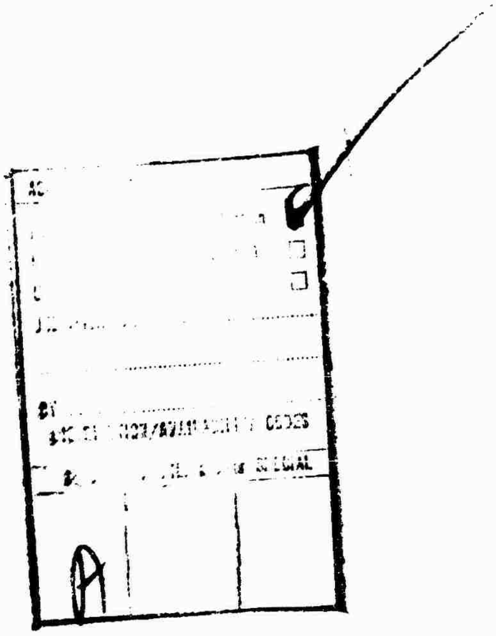

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AIR FORCE/56780/20 August 1973 — 150

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Boeing Aerospace Company (A Division of The Boeing Co) P.O. Box 3999 Seattle, Washington 98124	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP ---

3. REPORT TITLE
STOL Tactical Aircraft Investigation, Vol. III
Takeoff and Landing Performance Ground Rules for Powered Lift STOL Transport Aircraft

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Technical Report, 8 June 1971 through 8 December 1971

5. AUTHOR(S) (First name, middle initial, last name)
Franklyn J. Davenport
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Vernon F. Van Heyningen

6. REPORT DATE May 1973	7a. TOTAL NO. OF PAGES ~~49~~ 59	7b. NO. OF REFS 9

8a. CONTRACT OR GRANT NO. F33615-71-C-1757 b. PROJECT NO. 643A c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) D180-14403-1 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFFDL-TR-73-19, Volume III

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Air Force Flight Dynamics Laboratory Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

Rules for determining takeoff and landing distances of STOL transport airplanes equipped with powered-lift systems are proposed and discussed. These rules relate to speed margins and maneuvering capability required for safe operations and to the procedures for computation of required runway lengths. The most significant difference between the proposed rules and "conventional" performance rules is that speed margins and maneuver g - margins should be based on the airplane's capability with power on.

Procedures for calculation of powered-lift STOL performance are stated in detail.

DD FORM 1 NOV 65 1473

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
STOL						
Powered lift						
Performance rules						

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FOREWORD

This report was prepared for the United States Air Force by The Boeing Company, Seattle, Washington in partial fulfillment of Contract F33615-71-C-1757, Project No. 643A. It is one of eight related documents covering the results of investigations of vectored-thrust and jet-flap powered lift technology, under the STOL Tactical Aircraft Investigation (STAI) Program sponsored by the Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The relation of this report to the others of this series is indicated below:

AFFDL TR-73-19	STOL TACTICAL AIRCRAFT INVESTIGATION	
Vol I	Configuration Definition: Medium STOL Transport with Vectored Thrust/Mechanical Flaps	
Vol II Part I	Aerodynamic Technology: Design Compendium, Vectored Thrust/Mechanical Flaps	
Vol II Part II	A Lifting Line Analysis Method for Jet-Flapped Wings	
Vol III	Takeoff and Landing Performance Ground Rules for Powered Lift STOL Transport Aircraft	THIS REPORT
Vol IV	Analysis of Wind Tunnel Data: Vectored Thrust/Mechanical Flaps and Internally Blown Jet Flaps	
Vol V Part I	Flight Control Technology: System Analysis and Trade Studies for a Medium STOL Transport with Vectored Thrust/Mechanical Flaps	
Vol V Part II	Flight Control Technology: Piloted Simulation of a Medium STOL Transport with Vectored Thrust/Mechanical Flaps	
Vol VI	Air Cushion Landing System Study	

The work reported here was performed in the period 8 June 1971 through 8 December 1971 by the Aero/Propulsion Staff of the Research and Engineering Division and by the Tactical Airlift Program, Aeronautical and Information Systems Division, both of the Aerospace Group, The Boeing Company. Mr. Franklyn J. Davenport served as Program Manager.

The Air Force Project Engineer for this investigation was Mr. Garland S. Oates, Air Force Flight Dynamics Laboratory, PTA, Wright-Patterson Air Force Base, Ohio.

The main body of this report was released within The Boeing Company as Document D180-14403-1, and submitted to the USAF in December 1971. The report was resubmitted, after major format revisions to assure suitability for publication by the USAF, minor text changes, and addition of the Appendix, in December 1972.

This technical report has been reviewed and is approved.

E. J. Cross Jr.

E. J. Cross Jr., Lt. Col., USAF
Chief, Prototype Division
Air Force Flight Dynamics Laboratory

ABSTRACT

Rules for determining takeoff and landing distances of STOL transport airplanes equipped with powered-lift systems are proposed and discussed. These rules relate to speed margins and maneuvering capability required for safe operations and to the procedures for computation of required runway lengths. The most significant difference between the proposed rules and "conventional" performance rules is that speed margins and maneuver g - margins should be based on the airplane's capability with power on.

Procedures for calculation of powered-lift, STOL performance are stated in detail.

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SYMBOLS

C_D	Drag Coefficient
C_J	Thrust Coefficient
C_L	Lift Coefficient
C_W	Weight Coefficient
q	Dynamic Pressure, lbs/sq ft
S	Wing Area, sq ft
V_B	Initial Braking Speed, knots
V_{CO}	Climbout Speed, knots
V_F	Engine Failure Speed, knots
V_{FR}	Engine Failure Recognition Speed, knots
V_{LO}	Liftoff Speed, knots
V_{min}	Minimum Flight Speed, knots
V_{mca}	Air Minimum Control Speed, knots
V_{mlo}	Minimum Liftoff Speed, knots
V_{mtd}	Minimum Touchdown Speed, knots
V_R	Takeoff Rotation Speed, knots
V_{TD}	Touchdown Speed, knots
V_{TH}	Threshold Speed, knots
Δn	Normal Acceleration Margin, g's
α	Angle of Attack, deg
γ	Flight Path Angle, deg
η_T	Thrust Vectoring Efficiency
μ	Friction Coefficient
σ	Thrust Vector Angle, deg

SECTION I

SUMMARY AND INTRODUCTION

1.1 Summary

This document constitutes the "STOL Takeoff and Landing Specification Data Report" prepared by The Boeing Company for the U. S. Air Force Flight Dynamics Laboratory under contract number F33615-71-C-1757, "STOL Tactical Aircraft Investigation".

It presents a set of rules, summarized in Figures 1 and 2, for determining takeoff and landing speeds and field lengths for STOL airplanes which use "powered lift" to permit flight at speeds lower than the power-off stall speed. These rules are proposed to supplement those given in MIL-C-5011A (Ref. 1) and will permit consistent, meaningful comparison of the performance capability of STOL aircraft designs in configuration studies and proposal evaluation.

1.2 Introduction

1.2.1 Background

The U.S. Air Force has determined the requirement to modernize its Tactical Airlift capability. The Tactical Airlift Technology Advanced Development Program (TAT-ADP) was established as a first step in meeting this requirement, contributing to the technology base for development of an Advanced Medium STOL Transport (AMST).

The AMST must be capable of handling substantial payloads and using airfields considerably shorter than those required by large tactical transports now in the Air Force inventory. If this short-field requirement is to be met without unduly compromising aircraft speed, economy, and ride quality, an advanced-technology powered-lift concept will be required.

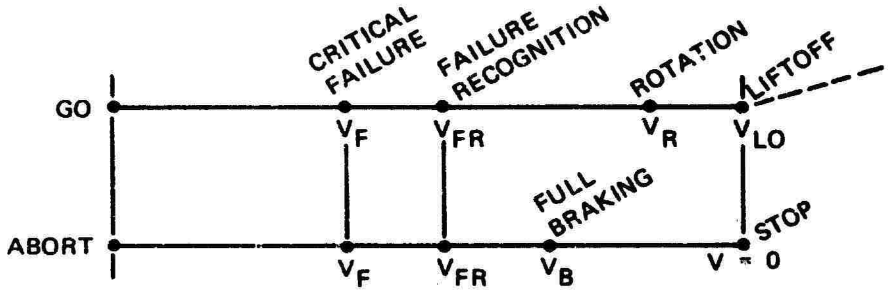
The STOL Tactical Aircraft Investigation (STAI) is a major part of the TAT-ADP, and comprises studies of the aerodynamics and flight control technology of powered lift systems under consideration for use on the MST. Under the STAI, The Boeing Company was awarded Contract No. F33615-71-C-1757 by the USAF Flight Dynamics Laboratory to conduct investigations of the technology of the vectored-thrust powered lift concept. These investigations included:

(1) Aerodynamic analysis and wind tunnel testing
(2) Configuration studies
(3) Control system design, analysis, and simulation

Takeoff and landing ground rules are the "bridge" relating the first two of these topics, since they determine the configuration benefits obtainable by application of new aerodynamics technology. The

DISTANCE

- **NORMAL:** CRITICAL FIELD LENGTH; SPEED, MANEUVER AND CLIMB MARGINS DETERMINED WITH ONE ENGINE OUT



- **ASSAULT:** DISTANCE TO LIFTOFF, SPEED, MANEUVER AND CLIMB MARGINS DETERMINED WITH ALL ENGINES OPERATING

SPEED MARGINS

- $V_{LO} \geqslant 1.08$ Vmlo

  $\geqslant 1.10\ V_{min}$ (1g, FREE AIR)
- $V_R \geqslant V_{FR}$
- V_{mlo} MAY BE DETERMINED BY:
  1. STALL IN GROUND EFFECT
  2. PITCH ATTITUDE LIMIT

MANEUVER "g" MARGIN

- $\Delta n > 0.10g$ @ V_{LO}, IN GROUND EFFECT

CLIMB GRADIENT

- $\gamma > 3\%$ @ V_{LO}, IGE, GEAR DOWN

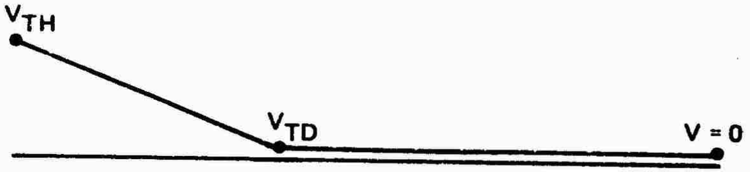
  $> 3\%$ @ V_{LO}, OGE, GEAR UP

BRAKING COEFFICIENT = 0.30
ROLLING COEFFICIENT = 0.04

Figure 1 : Proposed Takeoff Ground Rules – Summary

DISTANCE

- NORMAL: AIR DISTANCE FROM 50 FT PLUS STOPPING DISTANCE; SPEED, MANEUVER AND CLIMB MARGINS DETERMINED WITH ENGINE OUT: NO FLARE AT TOUCHDOWN.



- ASSAULT: STOPPING DISTANCE + 300 FT; MARGINS DETERMINED WITH ALL ENGINES OPERATING.

SPEED MARGINS

- $V_{TH} \geqslant 1.2\ V_{min}$
- $V_{TD} \geqslant 1.1\ V_{mtd}$

MANEUVER MARGINS

- $\Delta n \geqslant 0.30g$ @ V_{TH}
- $\Delta n \geqslant 0.15g$ @ V_{TD}

V_{mtd} MAY BE DETERMINED BY:
1. STALL IN GROUND EFFECT
2. PITCH ATTITUDE LIMIT

TOUCHDOWN RATE OF SINK

- R/S $\leqslant$ 2/3 LANDING GEAR DESIGN RATE OF SINK

TRANSITION TIME

- MANUAL SPOILERS – 2 SECONDS
- AUTOMATIC SPOILERS – ½ SECOND

FIELD CONDITION

- DRY, HARD DIRT
  (μ_B = 0.3 WITH NO REVERSE THRUST)

Figure 2: *Proposed Landing Ground Rules – Summary*

rules specified in MIL-C-5011A (Ref. 1), the most frequently used performance basis for proposals and design studies, are unsuitable for evaluating modern STOL airplane concepts because they give no credit for powered lift. "Ad Hoc" STOL ground rules have had to be formulated for recent studies and programs, such as the Light Intra-Theater Transport (LIT), the "readily available" Light STOL Transport (LST), and the Baseline Configuration Study portion of the present STAI. A new set of rules, framed to meet the general requirements of powered-lift STOL is therefore needed.

1.2.2 Military Rules vs Civil Rules

The problem of STOL performance ground rules has been studied before, although most attention has been given to commercial aviation requirements. NASA TN D-5594 and FAR Part XX (References 2 and 3) both treat the subject, but commercial STOL is still a thing of the future, and Part XX remains tentative.*

The most striking difference between civil and military transport aviation ground rules is the fact that in some circumstances, military needs justify operation in conditions where engine failure would result in loss of the airplane. Two sets of rules are therefore set forth in this report:

(1) "Normal" rules, for everyday, routine operation, allowing for a single major failure. These provide a degree of safety comparable to commercial transport rules. Either a safe abort or a safe continuation of takeoff or landing can be made following engine failure.

(2) "Assault" rules, for operations where full advantage is taken of the airplane's performance capability with all engines operating, but where engine failure would probably cause a crash or forced landing.

1.2.3 Objectives

In framing ground rules for STOL performance, it would also be well to recall that the purpose of these rules is not to define airworthiness requirements in great detail for purposes of certification or of flight manual preparation. It is, rather, to guide designers and configuration evaluators. This means that the rules should be:

---

*Flying qualities required for STOL have received much attention. They are discussed in Ref. 2, and a military specification (MIL-F-83300, Ref. 4) has been issued. (That document is currently being reviewed and may be revised.) Flying qualities specifications pertain to takeoff and landing ground rules because they may define minimum acceptable control power, which must be considered in selection of takeoff and landing speeds. That is the only respect in which flying qualities will be referred to in this report.

(1) Simple enough to be easily applied to a large number of designs that are to be compared.

(2) "Responsive" to design characteristics. The rules must motivate the designer to take realistic advantage of technological innovations.

1.2.4 Document Organization

Section II of this document states the rules recommended as a result of this study. Section III discusses them and compares them to other sets of ground rules, STOL and CTOL, civil and military. Section IV shows how these apply to the Baseline Configuration vectored-thrust airplane defined in an earlier portion of the Boeing STAI program. Appendix A provides details of the calculation methods used in determining STOL performance data shown in this and other volumes in the series reporting the results of The Boeing Company's portion of the STAI.

SECTION II

PROPOSED PERFORMANCE GROUND RULES

2.1 Scope

The rules given here are applicable to multi-engined STOL aircraft with powered lift systems. Aircraft capable of hovering over a fixed point in zero wind (VTOL) are not covered by this specification.

STOL criteria are presented for both "normal" operation and "assault" (maximum effort) operation. "Normal" takeoffs and landings allow for critical system failures such as an engine failure during takeoff or a brake failure on landing. "Assault" rules assume that all systems function properly.

2.2 General Performance Criteria

Performance must be determined without requiring exceptional piloting skill, alertness, or strength. The available thrust must not exceed the approved ratings less installation losses and the thrust absorbed by the accessories, services, and flight controls.

2.3 Reference Minimum Speeds

2.3.1 Minimum Flight Speed

V_{min} - The lowest speed at which the aircraft is controllable in steady 1"g" flight out of ground effect. The minimum speed may be a conventional stall, or may be established by a control limit, by objectionable buffeting, or by undesirable pitching and rolling moments. V_{min} shall be determined for all appropriate flight configurations:

(1) With powerplants supplying power output levels for normal operation in the applicable flight configuration.

(2) At the appropriate weight, elevation, and temperature for which the minimum speed is being determined.

(3) At the most unfavorable center of gravity within the allowable limits.

(4) With the critical powerplant component supplying propulsion, and/or lift, and/or control, inoperative. (Except for "assault")

2.3.2 Minimum Liftoff Speed

V_{mlo} - The lowest speed at which the airplane can lift off the ground and continue the takeoff. This may be the stall speed <u>in ground effect</u>, with the main wheels on the ground and oleo extended, or may be established by a pitch attitude limit (aft body ground contact),

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control limit, objectionable buffeting, or undesirable pitching or rolling moments. V_{mlo} shall be determined for all takeoff configurations:

(1) With powerplants supplying power output levels for takeoff.

(2) At the appropriate weight, elevation and temperature for which the minimum speed will be used.

(3) At the most unfavorable center of gravity within the allowable limits.

(4) With the critical powerplant component supplying propulsion, and/or lift, and/or control, inoperative. (Except for "assault")

2.3.3 Minimum Touchdown Speed

V_{mtd} - The lowest speed at which the airplane can touch down. This may be the stall speed in ground effect with the main gear wheels on the ground and oleo extended, or may be established by a pitch attitude limit (aft body ground contact), control limit, by objectionable buffeting, or by undesirable pitching or rolling moments. V_{mtd} shall be determined for all landing configurations:

(1) With powerplants supplying power output levels for normal operation at touchdown.

(2) At the appropriate weight, elevation, and temperature for which the minimum speed shall be used.

(3) At the most unfavorable center of gravity within the allowable limits.

(4) With the critical powerplant component supplying propulsion and/or lift, and/or control, inoperative. (Except for "assault")

2.4 Normal Takeoff

Normal takeoff distances shall be based on the total distance to accelerate on all engines to the critical powerplant failure speed, experience a critical powerplant failure, then to continue the takeoff with the remaining powerplants, or to stop in the remaining distance. This is the same as the Critical Field Length for conventional aircraft and is shown in the upper half of Figure 3.

2.4.1 Critical Powerplant Failure

For STOL aircraft, the critical failure is the failure of the powerplant component supplying propulsion, and/or lift, and/or control, the loss of which would most degrade performance or control. Aircraft with propellers driven by separate engines through cross-shafting must allow for either a propeller failure or an engine failure. Also, aircraft with fans driven by gas generators through cross-ducting

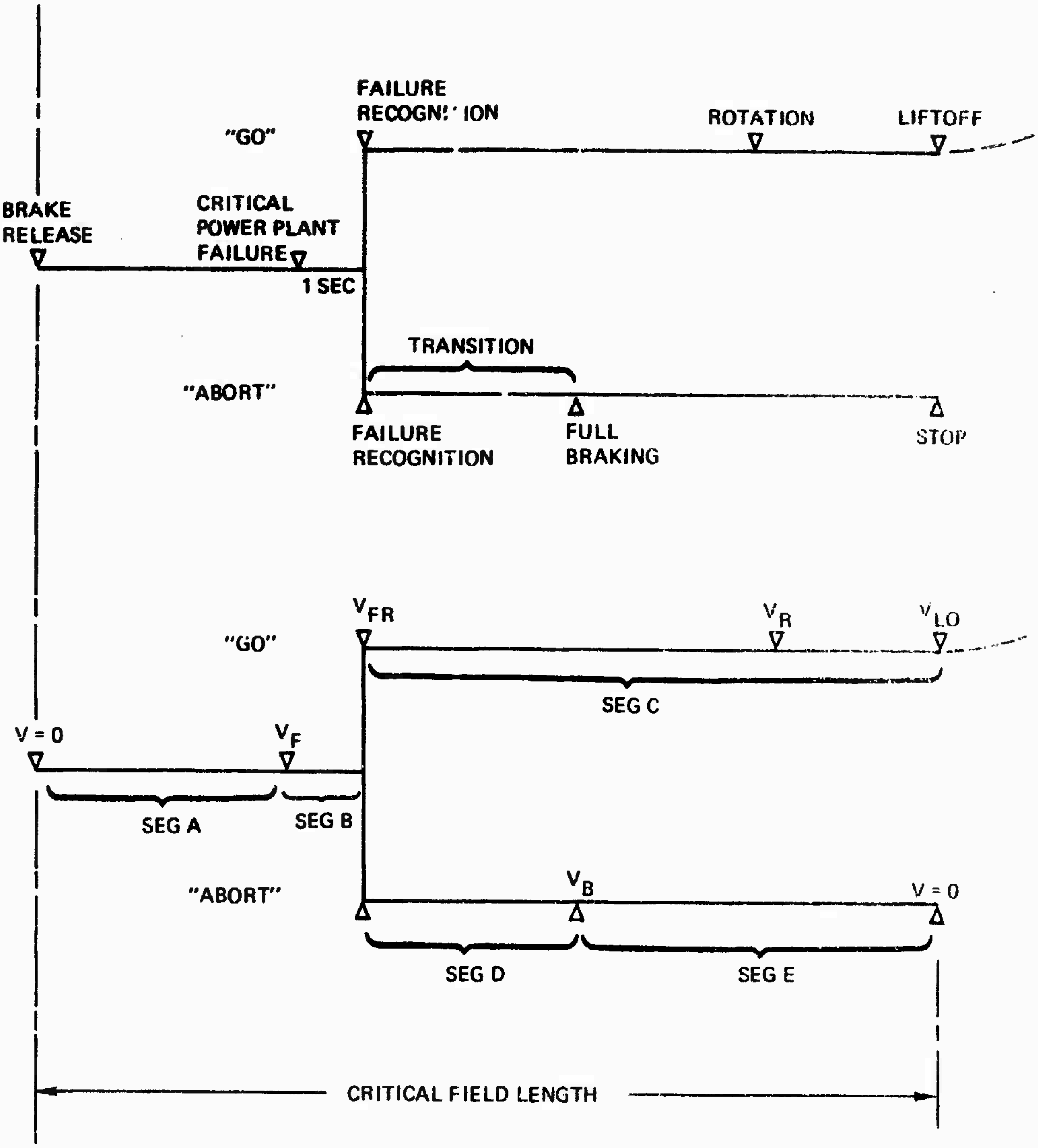

Figure 3: Critical Field Length

must allow for either a fan failure or a gas generator failure, whichever is more adverse.

2.4.2 Critical Field Length Segments (Refer to Figure 3)

Segment A is the acceleration distance to the powerplant failure speed, V_F, where all engines are operating at normal takeoff power.

Segment B is the acceleration distance from the failure speed, V_F, to the failure recognition speed, V_{FR}. One second is allowed to detect the failure from the instruments. Thrust loss for the failing powerplant shall be ignored during this second.

Segment C is the critical powerplant-inoperative acceleration from V_{FR} to liftoff. Any windmilling drag or the aerodynamic drag due to controlling asymmetric thrust must be added to the basic airplane drag for determining the acceleration in Segment C and the subsequent climbout performance.

Segment D is the transition distance between recognition of the failure and the establishment of the full braking configuration. Three seconds are allowed for 1) brake application; 2) thrust reduction to idle; speed brake actuation. During the transition, the speed increases initially, then decreases so the initial braking speed is assumed equal to V_{FR}.

Segment E is the braking distance for the refused takeoff. No credit for thrust reversal is taken during this segment, but full braking is assumed.

2.4.3 Rolling and Braking Coefficients

Usually STOL takeoff distances shall be for unsurfaced airstrips having a r lling coefficient of friction of .04, and a braking coefficient of .30 (dry, hard dirt).

2.4.4 Normal Takeoff Speeds

Note: In determining normal acceleration or climb capability as required in the definitions to follow (as well as in those given in the sections on landing), credit may be taken for "configuration changes", provided that:

(1) The flight control concept embodied in the design is such that the "configuration change" is accomplished by normal operation of the control system*, or through a pilot action consistent with normal (i.e., not emergency) procedures.

(2) The probability of failure of the mechanism(s) effecting the configuration change can be expected to be no greater than the probability of engine failure or other major propulsion system component failure.

V_{mcg} - Ground minimum control speed. V_{mcg} is the minimum speed at which controllability is demonstrated during the takeoff run to be adequate to permit proceeding safely with the takeoff using average piloting skill, when the critical powerplant is suddenly made inoperative.

V_{FR} - Critical powerplant failure recognition speed. V_{FR} shall not be less than V_{mcg}.

V_{mca} - Air minimum control speed. V_{mca} is the minimum control speed in the air with the critical powerplant inoperative. When the critical powerplant is suddenly made inoperative at this speed, it shall be possible to recover control of the airplane with the powerplant still inoperative, and maintain it in straight flight at that speed, with an angle of bank not in excess of 5°.

V_R - Takeoff rotation speed. V_R is the speed at which rotation is initiated. V_R shall not be less than V_{FR}.

V_{LO} - Liftoff speed. V_{LO} shall not be less than:

(1) 1.08 V_{mlo} with the critical powerplant inoperative.

(2) The minimum speed providing .1g normal acceleration margin with the critical powerplant inoperative, in ground effect with wheels touching, oleos extended.

(3) 1.10 V_{min} with the critical powerplant inoperative.

(4) 1.05 V_{mca} with the critical powerplant inoperative.

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*For example, a vectored-thrust airplane might control path angle by varying vector nozzle angle, at fixed engine thrust. To "wave off" from an approach, the pilot would pull back on the control column. The control system would then apply a combination of vector nozzle and elevator angle movement so as to pull up, ending at a vector angle corresponding to equilibrium flight at a positive path angle.

At V_{LO}, the climb gradient capability shall not be less than 3% with the critical engine inoperative, and

- Landing gear down, in ground effect,

  or

- Landing gear retracted, out of ground effect.

NOTE: In the same configuration as for liftoff, the airplane must be able to attain a flight condition for climbout which meets the following requirements with the critical engine inoperative, out of ground effect:

3% climb gradient

0.3g normal acceleration margin

$V_{CO} \geq 1.2\ V_{min}$

$V_{CO} \geq 1.1\ V_{mca}$

Normally, this condition is guaranteed by the requirement that $V_{LO} \geq 1.08\ V_{mlo}$. In that case, it does not affect takeoff performance. For some airplanes, especially with very high flap drag, this condition may restrict the flap setting for liftoff.

2.5 Assault Takeoff

No consideration is given to a powerplant failure and the liftoff and climbout speeds are reduced for the assault takeoff. The assault takeoff distance is the distance from brake release to liftoff with all engines at takeoff power (Figure 4). At liftoff, the airplane is flared to reach climbout speed at 50 feet (above the runway elevation) and then climbout at constant indicated airspeed. At gear up, the aircraft shall have a climb gradient of at least 3%.

2.5.1 Assault Takeoff Speeds

V_{LO} - Liftoff speed. The liftoff speed, V_{LO}, shall not be less than:

(1) 1.08 V_{mlo} with all engines operating.

(2) The minimum speed providing .1g normal acceleration margin with all engines operating, in ground effect with wheels touching, oleos extended.

At V_{LO}, the climb gradient capability in ground effect shall not be less than 3% with gear extended, all engines operating. In free air, the climb gradient shall not be less than 3% with the gear retracted and all engines operating.

2.6 Normal Landing

The normal landing distance shall be the distance to clear 50 feet and come to a complete stop.

2.6.1 Normal Landing Segments

The landing distance shall be determined in three segments as shown on Figure 5.

Air Distance - The air distance is based on 1) crossing the threshold (50 ft. above the airstrip) at a steady rate of sink no greater than 2/3 of the gear design sink speed, 2) no flare, and 3) touchdown at the threshold rate of sink.

Transition Distance - Manual spoilers: two seconds are allowed to lower the nose, apply brakes, and deploy spoilers. A 3% speed loss shall be assumed during transition. Automatic spoilers: 1/2 second transition time is allowed for aircraft with automatic spoilers that land in a near level ($\leq 5°$) attitude.

Braking Distance - The braking distance is the greater of the distances required to come to a complete stop on either:

(1) A dry unsurfaced airstrip (maximum braking coefficient = .30) without reverse thrust; or

(2) A wet unsurfaced airstrip (maximum braking coefficient = .15) with maximum normal reverse thrust. Any additional transition time required for thrust reversers shall be accounted for.

2.6.2 Normal Landing Speeds

Landing speeds for normal operation shall be selected to allow for the failure of the critical powerplant at any time during the approach and landing.

V_{TH} - The threshold speed, V_{TH}, is the final approach speed and is maintained down to 50 feet over the airstrip elevation. The threshold speed shall not be less than:

(1) 1.20 V_{min} with the critical powerplant inoperative.

(2) The minimum speed providing .30g normal acceleration margin with critical powerplant inoperative.

(3) 1.1 V_{mca}.

(4) The minimum speed permitting a climb gradient of 3% at full power, all engines operating, gear down, and 50 feet over airstrip elevation. A configuration change* is allowed provided the trim change is small and provided reasonable stall and maneuver margins are maintained.

---

*Flap setting, vector angle, or other adjustment depending on the airplane design.

V_{TD} - The touchdown speed, V_{TD}, shall not be less than:

(1) 1.10 V_{mtd} with the critical powerplant inoperative.

(2) The minimum speed permitting a normal acceleration margin of .15g, in ground effect at the height for touchdown with oleos extended, and one engine inoperative.

(3) V_{TH}, unless a means of deceleration during descent from 50 feet altitude to touchdown is defined.

2.7 Assault Landing

No consideration is given to a powerplant failure and the threshold and touchdown speeds are reduced for the assault landing. Threshold height is not specified. The landing distance (Figure 6) shall consist of an air distance segment of 300 ft., a normal transition segment, and a braking segment using all available stopping devices (maximum braking coefficient = 0.3). Any additional transition time required for thrust reversers shall be accounted for.

2.7.1 Assault Landing Speeds

V_{TH} - The threshold speed shall not be less than:

(1) 1.20 V_{min} with all engines operating.

(2) The minimum speed providing .30g normal acceleration margin with all engines operating.

(3) The minimum speed permitting a 3% climb gradient at full power, gear down, and 50 feet over airstrip elevation. A configuration change is allowed provided the trim change is small and provided the threshold stall and maneuver margins are maintained.

V_{TD} - The touchdown speed shall not be less than:

(1) 1.10 V_{mtd} with all engines operating.

(2) The minimum speed providing a normal acceleration of .15g in ground effect, at the height for touchdown, with oleos extended, with all engines operating.

(3) V_{TH}, unless a means of deceleration during descent from 50 feet altitude to touchdown is defined.

Figure 4 ASSAULT TAKEOFF DISTANCE

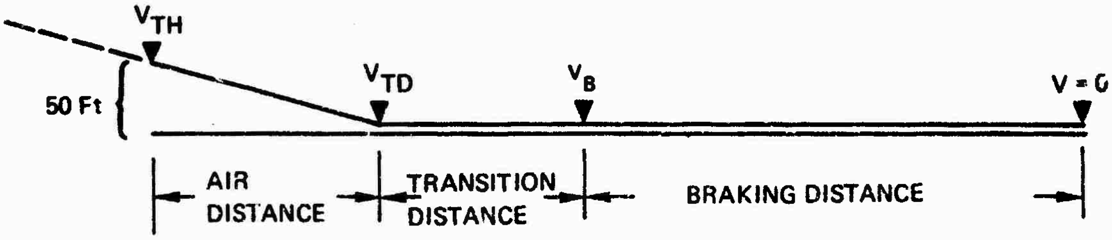

Figure 5 NORMAL LANDING DISTANCE

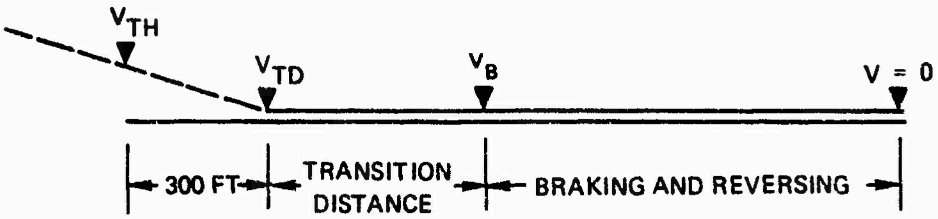

Figure 6 : Assault Landing Distance

SECTION III

DISCUSSION OF PROPOSED STOL GROUND RULES

3.1 Takeoff Rules

Table I summarizes and compares the various ground rules in use or proposed for takeoff performance determination.

3.1.1 Definition of Takeoff Distance

This report proposes to establish critical field length, instead of all-engine distance to 50 foot height, as the standard of takeoff distance. Critical field length is usually the shorter of the two, but it was felt that engine-out control characteristics should be reflected in the takeoff distance.

Furthermore, critical field length is more realistic, since it is the basis for weight limit determination in U. S. Air Force operations. (The Airlift Operations Manual (Ref. 5), paragraph 41.4.? states that the takeoff weight shall not exceed the weight corresponding to a critical field length equal to the available runway.)

The air distance portion of the older definition served to require the takeoff speed to be high enough to permit adequate climb performance. But engine-out climb is not specifically referred to in that way. Here the requirement for an 8% margin above minimum liftoff speed guarantees climb or acceleration capability, since V_{mlo} is defined as an engine-out condition for normal takeoffs.

Finally, air distance is hard to calculate. The optimum combination of longitudinal and normal acceleration must be determined iteratively*, and it seems improbable to expect a pilot to achieve that precision in the rotation and initial climb maneuver anyway.

3.1.2 Takeoff Speeds

The principal difference between CTOL and STOL rules appears here: Minimum speed is determined with power on, instead of off. Speeds recommended for failure recognition and rotation (V_{FR} and V_R) appear to be more conservative than those of FAR Part 25, but in fact correspond to roughly the same "Δ knots", considering the differences in takeoff speed between conventional and STOL aircraft. Thus, equivalent protection from following gusts is provided. Definition of the margin as a percent of speed is proposed here, however, for convenience in calculation.

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*See, for example, Reference 6.

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Table I: Comparative Summary of Takeoff Rules

	CTOL RULES		STOL RULES				
SOURCE / ITEM	MIL-C-5011A	FAR PART 25	FAR PART XX (TENTATIVE)	LST (RAD 0-123)	TAI BASELINE STUDY	PROPOSED MILITARY STOL RULES	
						NORMAL	ASSAULT
SPEEDS	$V_{LO} \geq 1.10 V_S$ $V_{CO} \geq 1.2 V_S$	$V_1 > V_{mcg}$ (OEI) $V_R > V_{FR}$ $> V_{mca}$ $V_{LO} > 1.1 V_{mlo}$ (AEO) $> 1.05 V_{mlo}$ (OEI) $V_{CO} > 1.2 V_S$ $> 1.1 V_{mca}$ $> V_{FR}$	$V_{LO} \geq 1.05 V_{mcg}$ (OEI) $\geq 1.05 V_{REF}$ (OEI) $V_{FR} \geq V_{mcg}$ (OEI) $\geq V_{REF}$ (OEI) $V_{CO} \geq V_{mca} + 15$ KTS $\geq 1.1 V_{mca}$	NORMAL $V_{LO} > 1.1 V_S$ POWER OFF OR V_{mca} $V_{CO} > 1.2 V_S$ POWER OFF OR V_{mca} ASSAULT $V_{LO} > 1.2 V_S$ POWER ON $V_{CO} > 1.2 V_S$ POWER ON	$V_{LO} > 1.2 V_{min}$ (OEI) $> V_{min}$ + KTAS (OEI) $> 1.1 V_{mca}$ (OEI) $V_{CO} > V_{LO}$	$V_F > V_{mcg}$ (OEI) $V_R > V_{FR}$ (OEI) $V_{LO} > 1.05 V_{mca}$ (OEI) $1.05 V_{mlo}$ (OEI) $1.10 V_{min}$ (OEI) $V_{CO} > 1.2 V_{min}$ (OEI) $\geq 1.1 V_{mca}$ (OEI)	$V_{LO} \geq 1.05 V_{min}$ (AEO) $V_{CO} \geq 1.10 V_{min}$ (AEO)
MANEUVER MARGINS					• 0.2g @ V_{LO} (AEO) • 0.1g @ V_{LO} (OEI) FLARE LOAD FACTOR @ $C_L < (C_{L_{MAX}})$ 0.9	• 0.30g @ V_{CO} (OEI) • 0.10g @ V_{LO} (OEI)	• 0.30g @ V_{CO} (AEO) • 0.10g @ V_{LO} (AEO)
CLIMB GRADIENT	100 FPM @ SL (OEI)	(OEI) • GEAR DOWN γ @ $V_{LO} > 0.5\%$ • GEAR UP γ @ $V_{CO} > 3\%$ γ 400 FT-1,500 FT > 1.7% γ FINAL SEG > 1.7%	(OEI) • GEAR DOWN γ @ $V_{LO} > 0.5\%$ OR 250FPM • GEAR UP γ @ $V_{CO} \geq 3\%$ OR 300FPM γ @ $\frac{400}{1,500} > 1.7\%$ OR 300 γ @ FINAL SEG > 1.7% OR 300		γ = 5.2% (OEI)	> 3% (OEI) • GEAR DOWN @ V_{LO} IN GRD. EFFECT @ V_{CO} IN FREE AIR • GEAR UP @ V_{LO} IN FREE AIR	> 3% (AEO)
FIELD LENGTH DEFINITION	(AEO) DIST TO 50 FT	GREATEST OF: • 1.15 x (AEO) DIST TO 35 FT • (OEI) GO DIST TO 35 FT • (OEI) ACC-STOP DIST	SAME AS PART 25	• ASSAULT GROUND RUN (AEO) • NORMAL DIST TO 50 FT (AEO)	(AEO) DIST TO 50 FT	GREATER OF • (OEI) DIST TO LIFTOFF • (OEI) ACC-STOP DIST	(AEO) DIST TO LIFTOFF
FIELD CONDITION (APPLIES TO LANDING ALSO)	ROLL μ = 0.025 BRAKE μ = 0.30	SMOOTH, DRY, HARD-SURFACED DEMONSTRATED BRAKING COEFF	DEMONSTRATED ON AN SURFACE SELECTED FOR CERTIFICATION	• DRY, HARD DIRT ROLL μ = 0.04 BRAKE μ = 0.30	ROLL μ = 0.1 BRAKE μ = 0.25	DRY, HARD DIRT ROLL μ = 0.04 BRAKE μ = 0.30	SAME AS NORMAL RULES

V_S = FAR STALL SPEED AEO = ALL ENGINES OPERATING OEI = ONE ENGINE INOPERATIVE

Climbout speed is not itself a parameter affecting critical field length, so it isn't specified here. It is important, however, to select a value of liftoff speed (V_{LO}) which will assure that the airplane can continue to accelerate (both along the flight path and normal to it) to reach an appropriate steady climb speed and angle. The 8% margin above V_{mlo} is adequate for for this purpose.*

3.1.3 Maneuver "g" Margins

Normal acceleration capability is implicitly specified in CTOL rules, because minimum speed is determined by power-off maximum lift coefficient. A speed of 1.2 V min thus guarantees a .44 g normal acceleration capability, not counting power effects, which would add a little more.

For STOL, explicit specification of normal "g" capability is needed because power setting and thrust vector angle affect it. Furthermore, the increment of maximum lift due to power tends to be independent of speed for vectored thrust, and to vary with the first (or somewhat lower) power of speed for jet flaps. As a result, a given ratio above minimum speed gives less "g" margin for powered lift airplanes than for conventional ones.

The full .44 "g" increment implied by CTOL rules is generally much more than is ever used. Furthermore, the relatively low speeds of STOL operation imply a reduced "g" requirement for a given turn radius. It is therefore considered that .3g is an adequate maneuvering margin for the climbout phase of flight.

In determining V_{LO}, a problem arises which was not generally recognized in the past: Reduction of lift due to ground effect. At the high lift coefficients characteristic of STOL (especially with jet flaps), when flying close to or rolling on the runway, the wing creates a sort of "tail wind". The reduced dynamic pressure results in an apparent reduction of lift coefficient, which may be greater than the increase due to the downwash reduction of "classical" ground effect theory. In any case, maximum lift is generally reduced, and occurs at a lower angle of attack than in free air.**

In specifying a normal "g" capability for V_{LO}, it is therefore necessary to require that it be achievable in ground effect. The

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*See note on climbout in Section 2.4.4.

**See Ref. 7, Section 2.2 for a discussion of ground effect for STOL aircraft.

proposed requirement of .1g is adequate to assure that the airplane can lift off. The adverse ground effect attenuates rapidly with height, so substantially more than .1g will be available soon after liftoff.

3.1.4 Climb Gradient

Gradient, rather than rate of climb, determines capability to clear terrain or obstacles. MIL-C-5011A requires 100 fpm with one engine out. This amounts to about .7% gradient at conventional jet takeoff speeds. Since STOL air fields are likely to be located in areas of rough topography, a requirement of 3% is proposed here.

3.1.5 Field Condition

On dry, paved surfaces, modern anti-skid braking systems can develop a friction coefficient (μ) in the range of .4 to .5. However, tactical airlift STOL operations are likely to be conducted on a variety of surfaces, mostly poorer than pavement. The values of μ proposed here correspond to dry hard dirt. This was selected as an appropriately representative type of field. The requirement that stopping distance take no credit for thrust reversal adds an extra margin for more adverse conditions. (See braking distance, Section 2.6.1.)

3.2 Landing Rules

Table II summarizes and compares ground rules in use or proposed for landing performance determination.

3.2.1 Definition of Landing Distance

The FAR Part 25 (civil CTOL) landing distance is 66% (92% for wet runway) longer than the one defined by MIL-C-5011A or other military landing rules. The extra length has been found necessary in commercial operation for a number of reasons, but largely to account for touchdown dispersion along the runway.

The apparent implication is that MIL-C-5011A is unconservative. Nevertheless, this report proposes to use the same definition, for the following reasons:

- The FAR Part 25 landing distance is based on demonstrated maximum effort braking, for which a modern airplane will develop a braking μ substantially larger than the .3 value for which credit is taken in the proposed rules.

- Touchdown dispersion for a STOL transport will be reduced by an order of magnitude relative to current CTOL airplanes because of steeper approach angle, no-flare touchdown, and the improvement in quality of the flight director instrumentation and displays to be expected from AMST flight control technology work.

Table II: Comparative Summary of Landing Rules

SOURCE / ITEM	EXISTING CTOL RULES		STOL RULES				
	MIL-C-5011A	FAR PART 25	FAR PART XX (TENTATIVE)	LST (RAD-0-123)	TAI BASELINE STUDY	PROPOSED MILITARY STOL RULES	
						NORMAL	ASSAULT
FIELD LENGTH DEFINITION	DIST FROM 50 FT	DIST FROM 50 FT ÷ 0.6 x 1.15 WHEN WET	DISTANCE FROM 35 FT ÷ 0.6	GROUND ROLL AND DIST FROM 50 FT (AEO) $\geq$ 2 SEC TRANSITION	DISTANCE FROM 50 FT WITH 2 THRUST REVS 6°/SEC MAX DEROTATION TRANS = 2 SEC	DISTANCE FROM 50 FT THRESHOLD HEIGHT	GROUND ROLL + 300 FT WITH REVERSERS
SPEEDS	$V_{TH} \geq 1.2 V_S$ $V_{TH} \geq 1.1 V_S$	$V_{TH} \geq 1.3 V_S$	$V_{TH} \geq 1.05 V_{mcs}$	NORMAL $V_{TH} \geq 1.25 V_S$ PWR OFF $V_{TD} \geq 1.1 V_S$ PWR OFF ASSAULT $V_{TH} \geq 1.15 V_S$ PWR OFF $V_{TD} \geq 1.1 V_S$ PWR OFF	$V_{TH} \geq 1.1 V_{mcs}$	V_{TH} $\geq 1.1 V_{mcs}$ (OEI) $\geq 1.20 V_{min}$ (OEI) $V_{TD} \geq 1.1 V_{mcd}$ (OEI)	$V_{TH} \geq 1.2 V_{min}$ (AEO) $V_{TD} \geq 1.1 V_{mcd}$ (AEO)
MANEUVER MARGINS					0.2g @ V_{TH} (AEO) 0.1g @ V_{TH} (OEI)	0.30g @ V_{TH} (OEI) 0.15g @ V_{TD} (OEI)	0.30g @ V_{TH} (AEO) 0.15g @ V_{TD} (AEO)
FLIGHT PATH GO-AROUND					R/S $\leq$ 2/3 GEAR DESIGN R/S NO FLARE	R/S $\leq$ 2/3 GEAR DESIGN R/S NO FLARE	SAME
CLIMB CAPABILITY		$\gamma \geq 2.7\%$ (OEI)APP FLAPS $\geq 3.2\%$ (AEO)LND FLAPS	(OEI) $\geq$2.7% OR 225 FPM $\geq$3.2% OR 250 FPM (AEO) @ 1.3 V_S			3% @ 50 FT (OEI)	3% @ 50 FT (AEO)

3.2.2 Speeds and Maneuver "g" Margins

The discussion of these topics presented in Sections 3.1.2 and 3.1.3 is largely applicable to landing as well as takeoff.

It will be noted that FAR Part 25 requires approach at 1.3 times stall speed. In fact, this corresponds more closely to 1.24 times V_{min}, because the stall speed determination procedure specified by the FAR* results in an apparent magnification of maximum lift coefficient due to dynamic effects.

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*Minimum speed reached in a maneuver conducted by pulling up the nose in a manner to reduce speed at 1 knot per second until stall occurs.

SECTION IV

APPLICATION TO THE STAI BASELINE CONFIGURATION AIRPLANE (VECTORED THRUST PLUS MECHANICAL FLAPS)

4.1 The STAI Baseline Configuration Airplane

As one of the first steps of the STAI program, a configuration study was conducted, resulting in definition of a baseline airplane designated as the Boeing Model 953-801. This design served as a reference airplane for wind tunnel test planning, simulation studies, etc. It was used as an example airplane on which to apply the rules proposed in this report. The 953-801 is described in detail in the Appendix to Volume I of the series of reports documenting the Boeing portion of the STAI (Reference 9). For convenience, important characteristics are also described in this volume. (While the 953-801 airplane differs in many ways from the refined configuration reported in the main body of Ref. 9, the similarity of the two airplanes is so close in the respects affecting takeoff and landing performance criteria that the results of this report are considered fully applicable to both airplanes.)

Figure 7 shows the general arrangement of the -801. Its principal dimensions and aerodynamic parameters are listed on the figure.

The wing is fitted with triple slotted Fowler flaps out to 75% span. The ailerons occupying the remainder of the trailing edge are drooped and blown when the flaps are lowered. Further lateral control is provided by spoilers over the whole flapped part of the span. Full span curved Krüger flaps, also with blowing BLC, are applied to the leading edge.

Figure 8 shows the lift and drag characteristics of this wing at the flap setting for STOL operation.

The four (scaled) Allison PD 351-2 turbofan engines, rated at 17,740 pounds SLST, are equipped with a thrust vectoring and reversing system of the type shown in Figure 9.

A translating sleeve serves to uncover the cascade vanes of the reversing and vectoring nozzles, and at the same time to block the plug-type cruise nozzle. Vectoring or reversing are selected by a rotating valve arrangement, also shown in Figure 9. The vector angle (σ) can be modulated between 45° and 75° by movement of the cascade vanes. Between 0° and 45°, the effective vector angle can be modulated by motion of the translating sleeve. In a partially open position, the flow is split between the vectoring cascade vanes and the cruise nozzle.

Figure 10 shows the estimated turning efficiency (η_T) of this arrangement. For $\sigma > 45°$, a constant value of .9 is obtained. Between 0° and 45°, the split-flow scheme leads to a straight line locus of possible operating conditions, as shown in Figure 10. The η_T of this concept is poorer than that of others in the 0-45° σ range, but it appears to offer major weight advantages. The estimated reversing efficiency of this arrangement is .5.

Figure 11 shows engine net and gross thrust at the takeoff power setting at sea level, 59°F, and at 2500 ft., 93°F.

4.2 Powered Lift Performance Method

The procedure outlined below was used to develop the climb and acceleration data required to establish speed margins.

4.2.1 Power-on Force Polar

The first step is construction of power-on polars at speeds covering the range of interest, here from 60 to 100 knots. The methodology of Ref. 7 for power effects was not available when the study reported in this volume was made. Therefore, polars were constructed by direct vector addition of ram drag and gross thrust at the appropriate nozzle angle to the estimated power-off polar. (I.e., zero interference between propulsive and aerodynamic effects was assumed.)

Figure 12 shows the polars for 80 knots at 100 percent power on all four engines, and diagrams the construction procedure. Note that C_D and C_L are plotted to the same scale.

To determine the operating point for a given weight, construct a circle about the origin, of radius C_W ($\equiv W/qS$). At each point on the circle, the aerodynamic force is just sufficient to balance the weight vector in flight at constant speed and path angle (γ). Now construct a line through the origin at the angle γ from the C_L axis, positive to the left. The intersection point of that line and the circle is the operating point. σ and α for that weight, speed, power setting, and path angle may then be read directly. For example, the point marked by the circle on Figure 14 is for a weight of 132,600 pounds, $\gamma = -3.8°$, $\sigma = 75°$, and $\alpha = 5°$.

Acceleration and climb capabilities are also readily obtained. The normal acceleration available is simply $\Delta C_L/C_W$, where C_L is measured from the operating point to the maximum C_L point of the appropriate polar curve. An example is shown on Figure 14: $\Delta n = .487g$ at $\sigma = 75°$. Similarly, longitudinal acceleration capability can be inferred from the margin of $\Delta C_D/C_W$, measured in the negative drag direction from the operating point. Steady climb capability is found by noting the intersection of the C_W circle with the appropriate force polar. In the present case, a climb angle $\gamma = +14.5°$ is available at $\sigma = 0°$, though the Δn available there is substantially reduced.

MODEL 953-801

AERODYNAMIC DATA

		WING	HORIZ. TAIL	VERT. TAIL
AREA	FT^2	1589.50	422.30	327.38
SPAN	FT	112.76	41.10	18.09
ASPECT RATIO		8.0	4.0	1.0
SWEEP, C/4		10°	10°	35°
DIHEDRAL		0°	- 4°	—
INCIDENCE		0°	+ 4°, -15°	—
TAPER RATIO		.3	.5	.8
THICKNESS RATIO	BODY SIDE	.150	.13	.13
	.55 b/2	.132	.13	.13
	TIP	.132	.13	.13
MAC	FT	15.46	10.65	18.17
VOLUME COEFFICIENT		—	1.10	0.10

POWER PLANT
4 [illegible] PASS 5.25 TURBOFANS WITH THRUST VECTORING 17,740 LB THRUST

LANDING GEAR

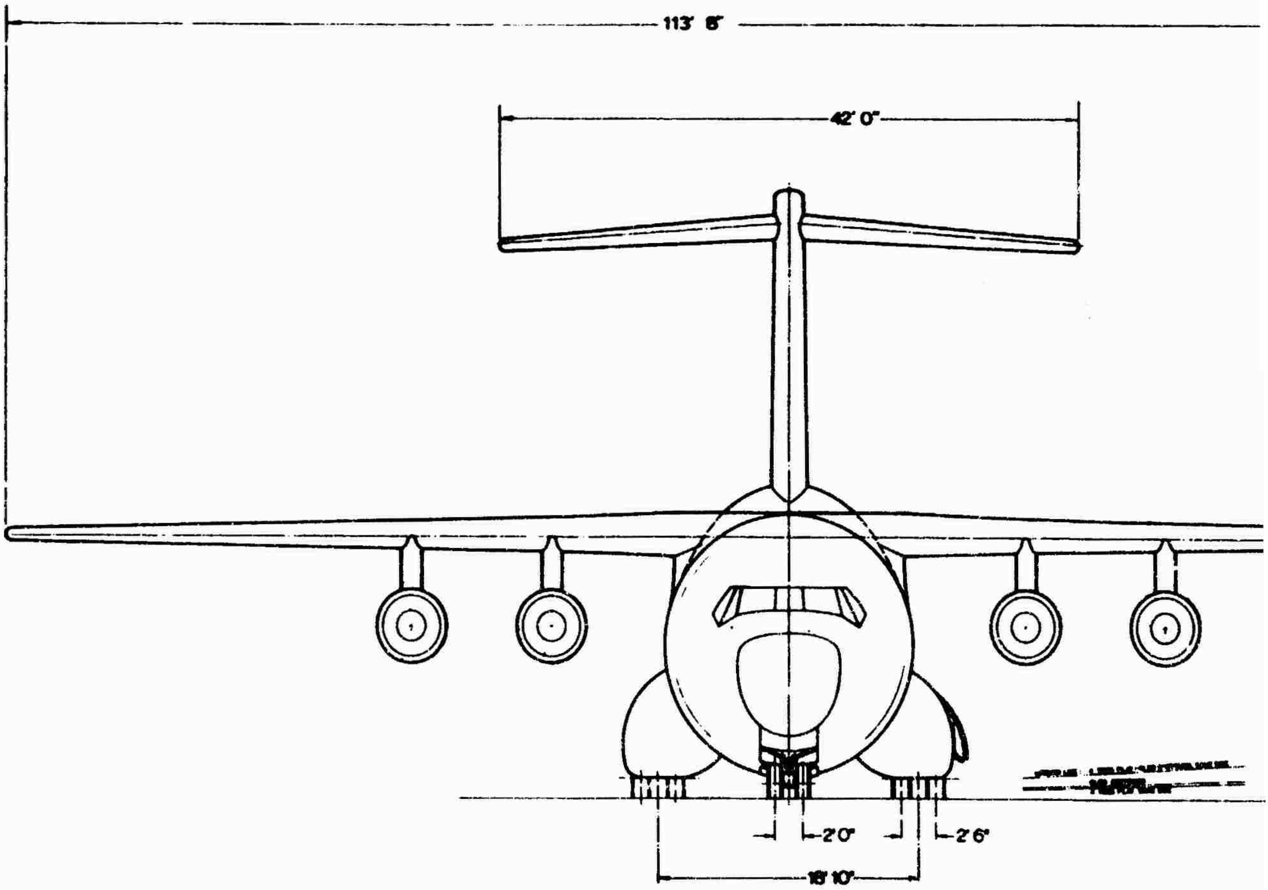
MAIN	8	42 x 15.0 - 16 TIRES
NOSE	2	34 x 12.0 - 12 TIRES

CARGO COMPARTMENT
144"W 144"/148"H 540"L

WEIGHTS

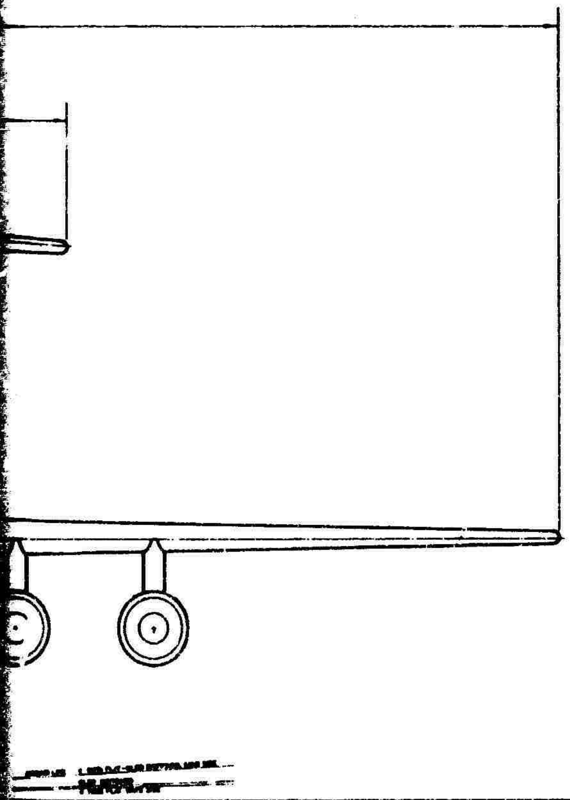
DESIGN GROSS	145,440	LB	ASSAULT MISSION
DESIGN STOL	132, 350	LB	
STOL PAYLOAD		LB	
O.E.W.	88,500	LB	
DESIGN GROSS	194,000	LB	CTOL MISSION
MAX. PAYLOAD		LB	

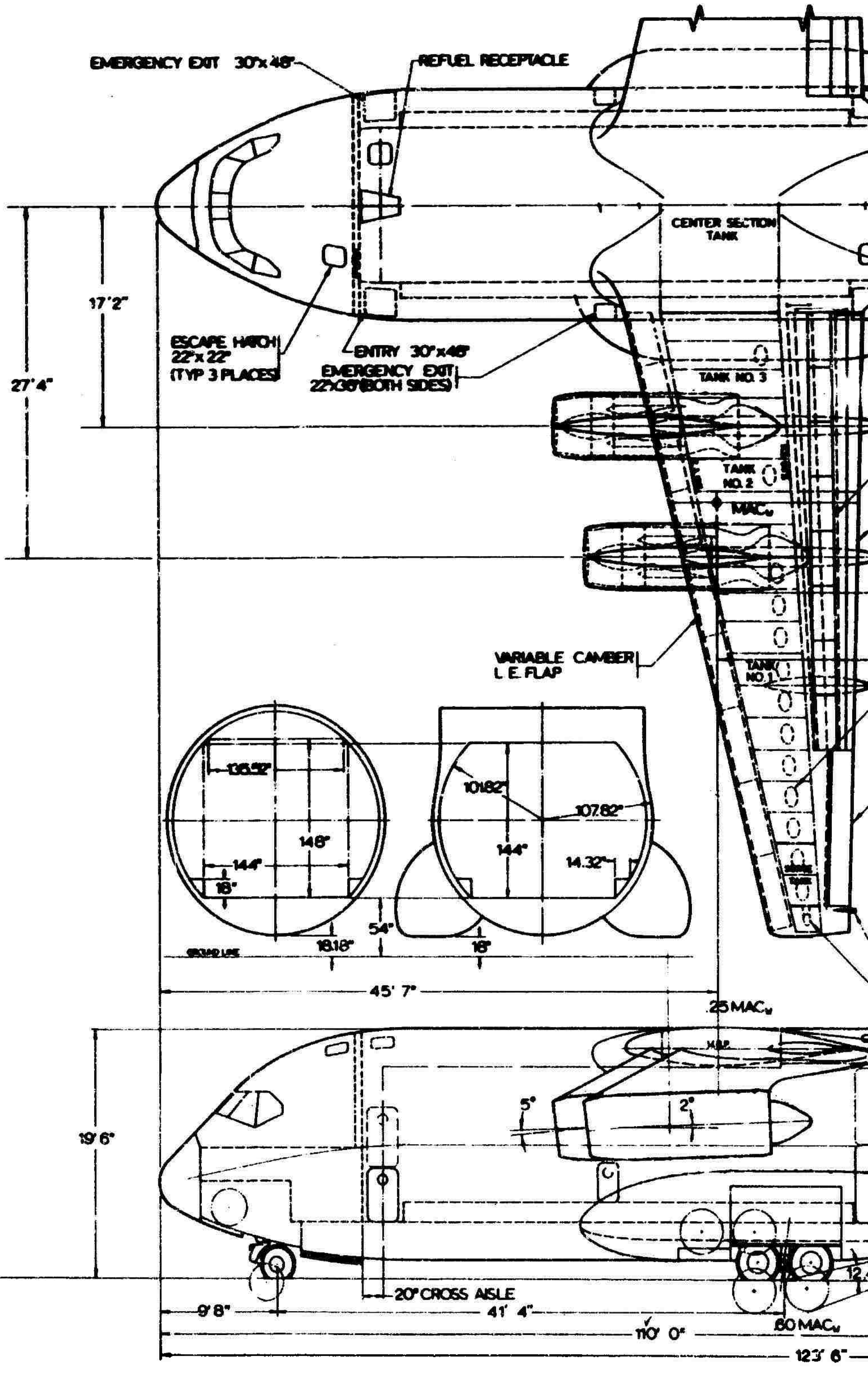
FUEL
TANK NO. 1 & 6
TANK NO. 2 & 5
TANK NO. 3 & 4
SUBTOTAL
CENTER TANK
TOTAL



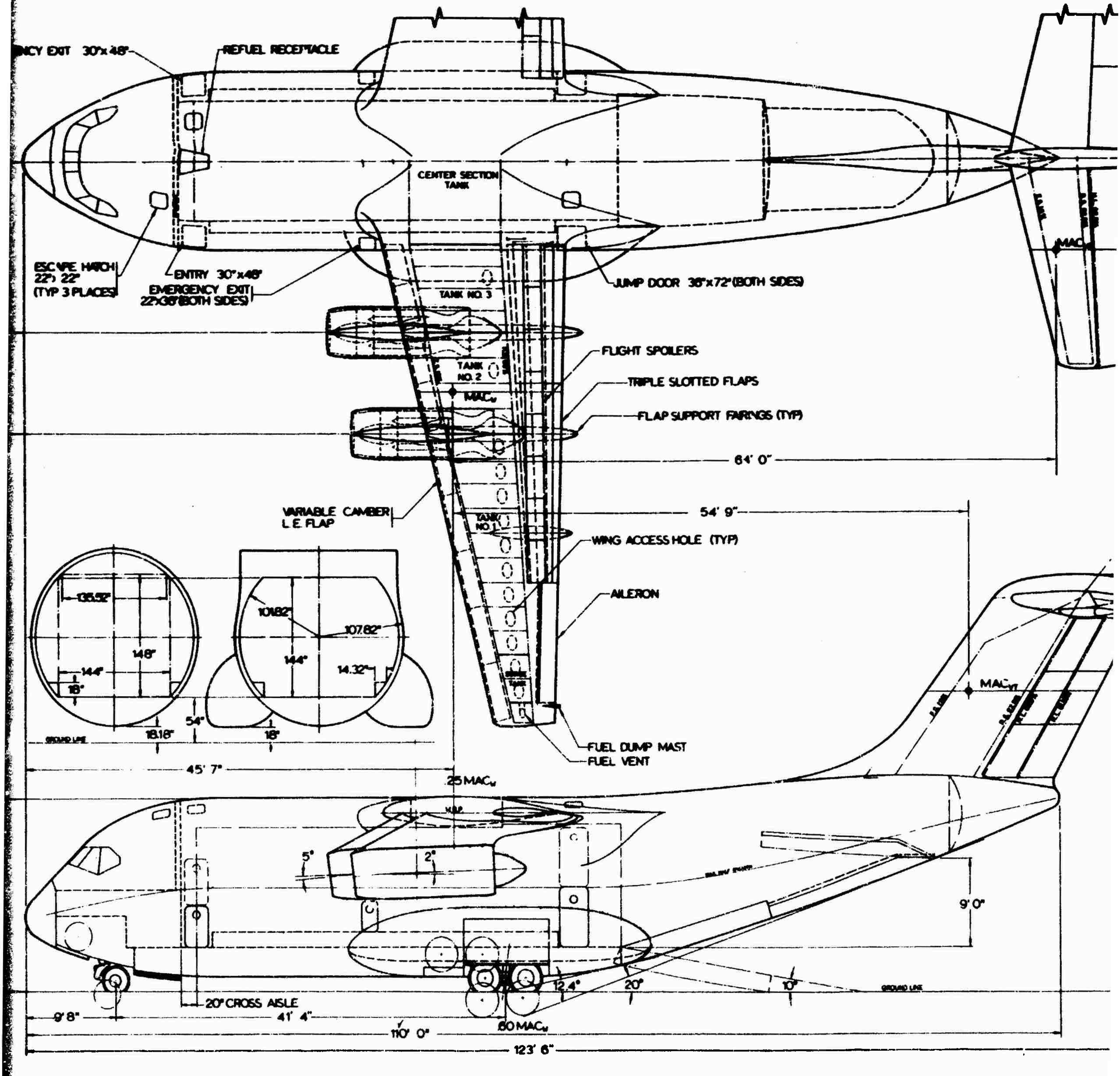
A

FUEL		
TANK NO. 1 & 6	14,180	LB
TANK NO. 2 & 5	13,760	LB
TANK NO. 3 & 4	17,170	LB
SUB TOTAL	45,110	LB
CENTER TANK	19,130	LB
TOTAL	64,240	LB





B


NCY EXIT 30"x 48"
REFUEL RECEPTACLE
CENTER SECTION TANK
ESCAPE HATCH 22") 22" (TYP 3 PLACES)
ENTRY 30"x48"
EMERGENCY EXIT 22"x38"(BOTH SIDES)
JUMP DOOR 38"x72"(BOTH SIDES)
TANK NO. 3
TANK NO. 2
MAC
FLIGHT SPOILERS
TRIPLE SLOTTED FLAPS
FLAP SUPPORT FAIRINGS (TYP)
64' 0"
54' 9"
VARIABLE CAMBER L.E. FLAP
TANK NO. 1
WING ACCESS HOLE (TYP)
AILERON
FUEL DUMP MAST
FUEL VENT
135.52"
148"
14.4"
18"
101.82"
107.82"
144"
14.32"
54"
18.18"
18"
GROUND LINE
45' 7"
.25 MAC
MAC
5°
2°
9' 0"
12.4°
20°
10°
GROUND LINE
20" CROSS AISLE
9' 8"
41' 4"
110' 0"
.60 MAC
123' 6"

C

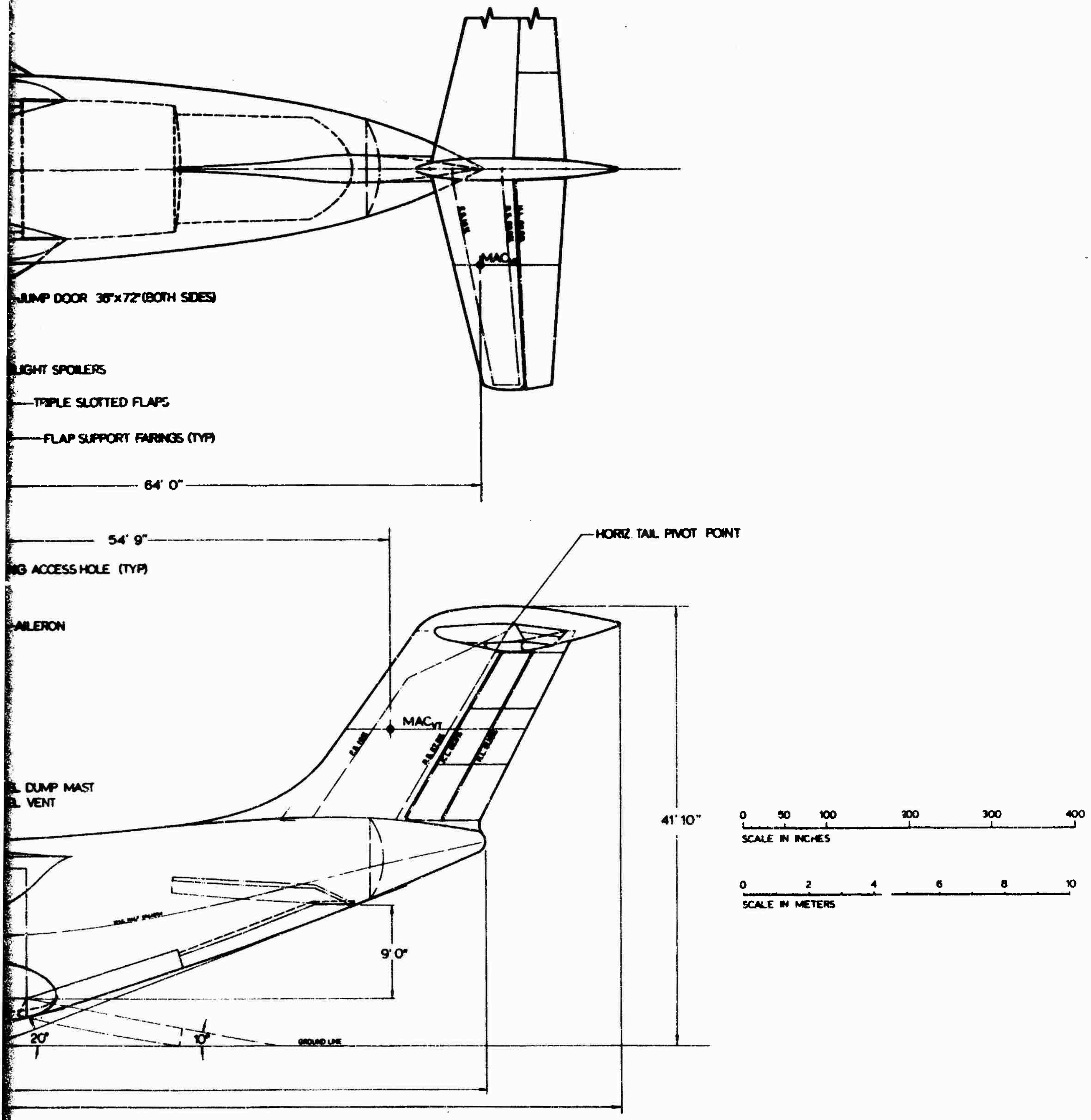


Figure 7 : General Arrangement – Model 953-801

D

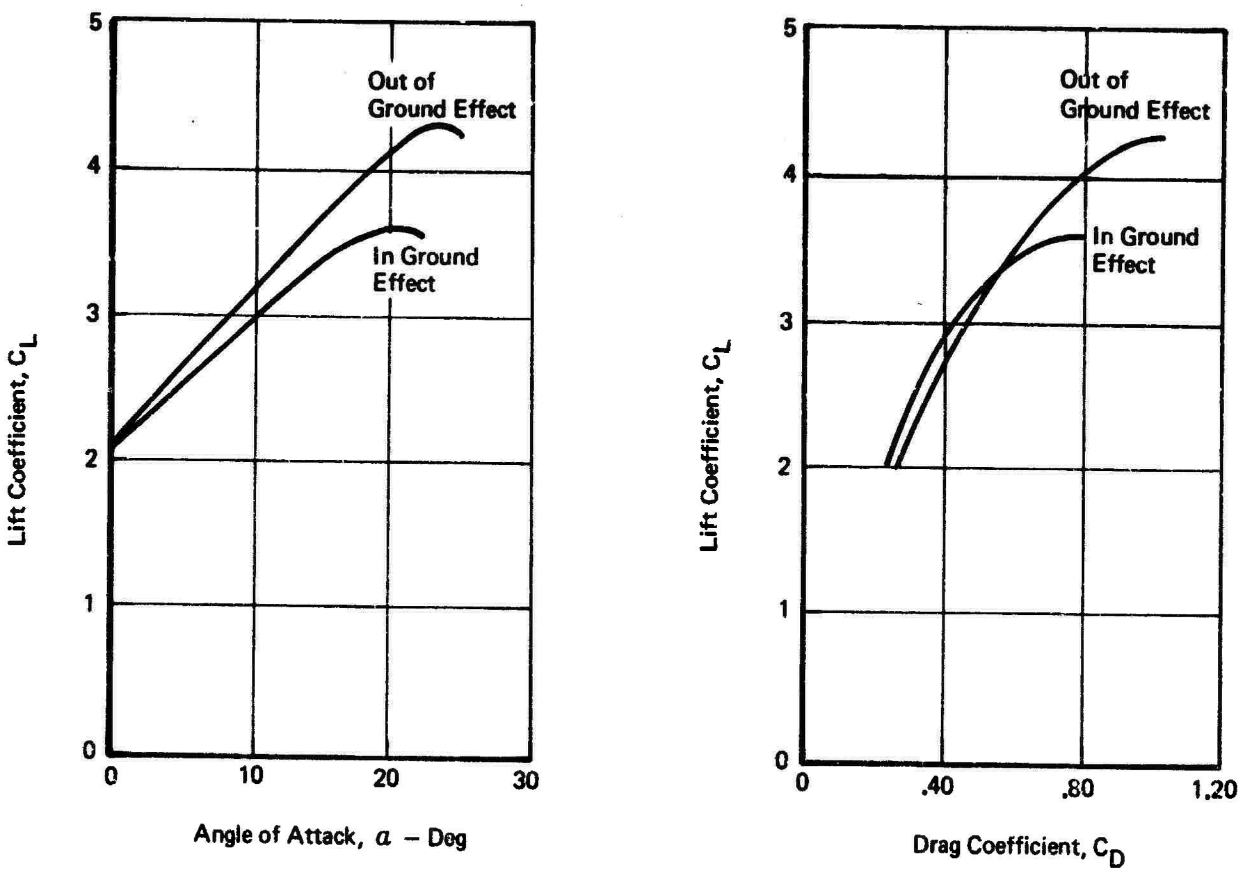


Figure 8: Flaps Down Aerodynamic Characteristics (Power Off)

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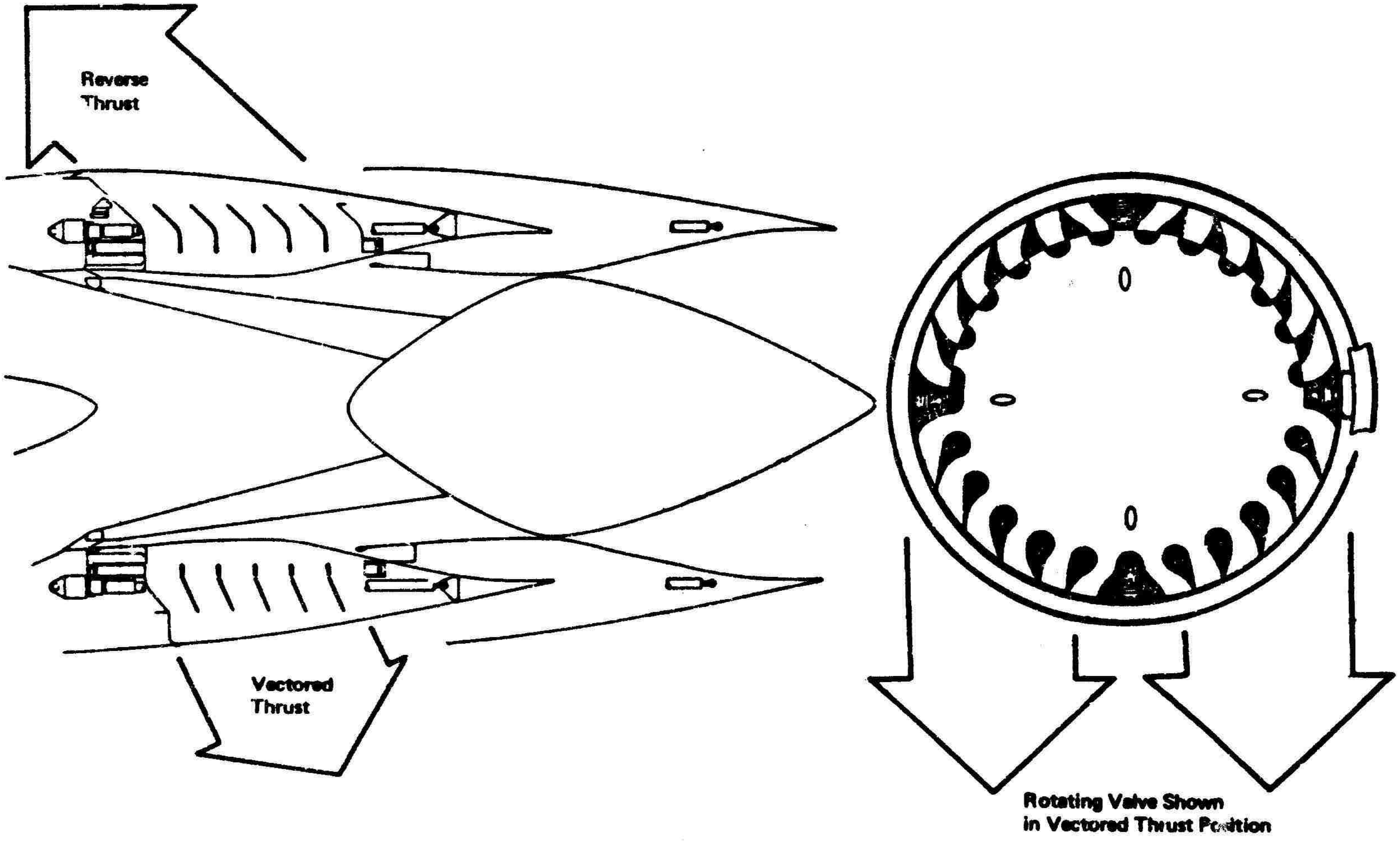


Figure 9: Thrust Reverser/Vectoring System—Rotating Valve Concept

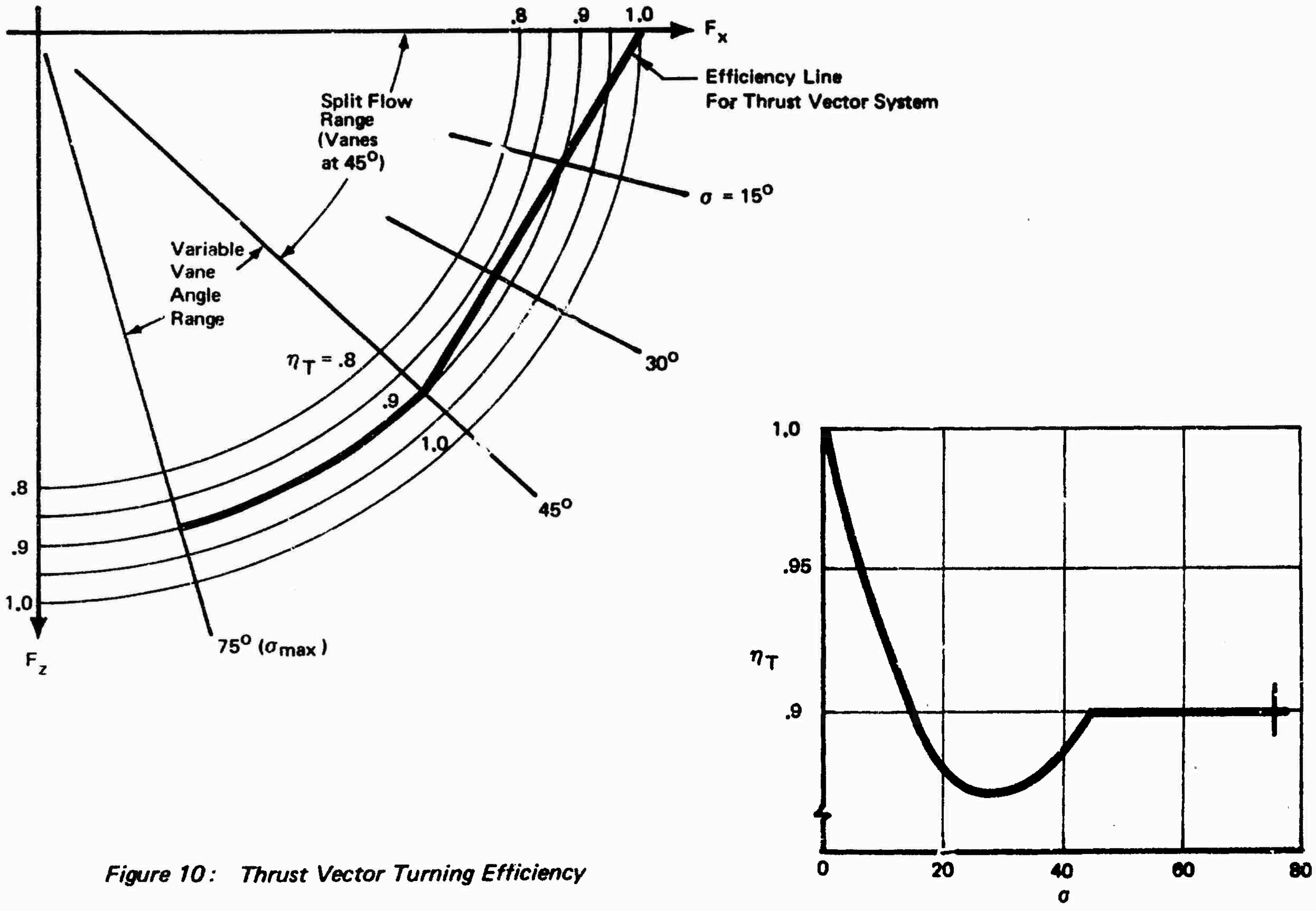


Figure 10: Thrust Vector Turning Efficiency

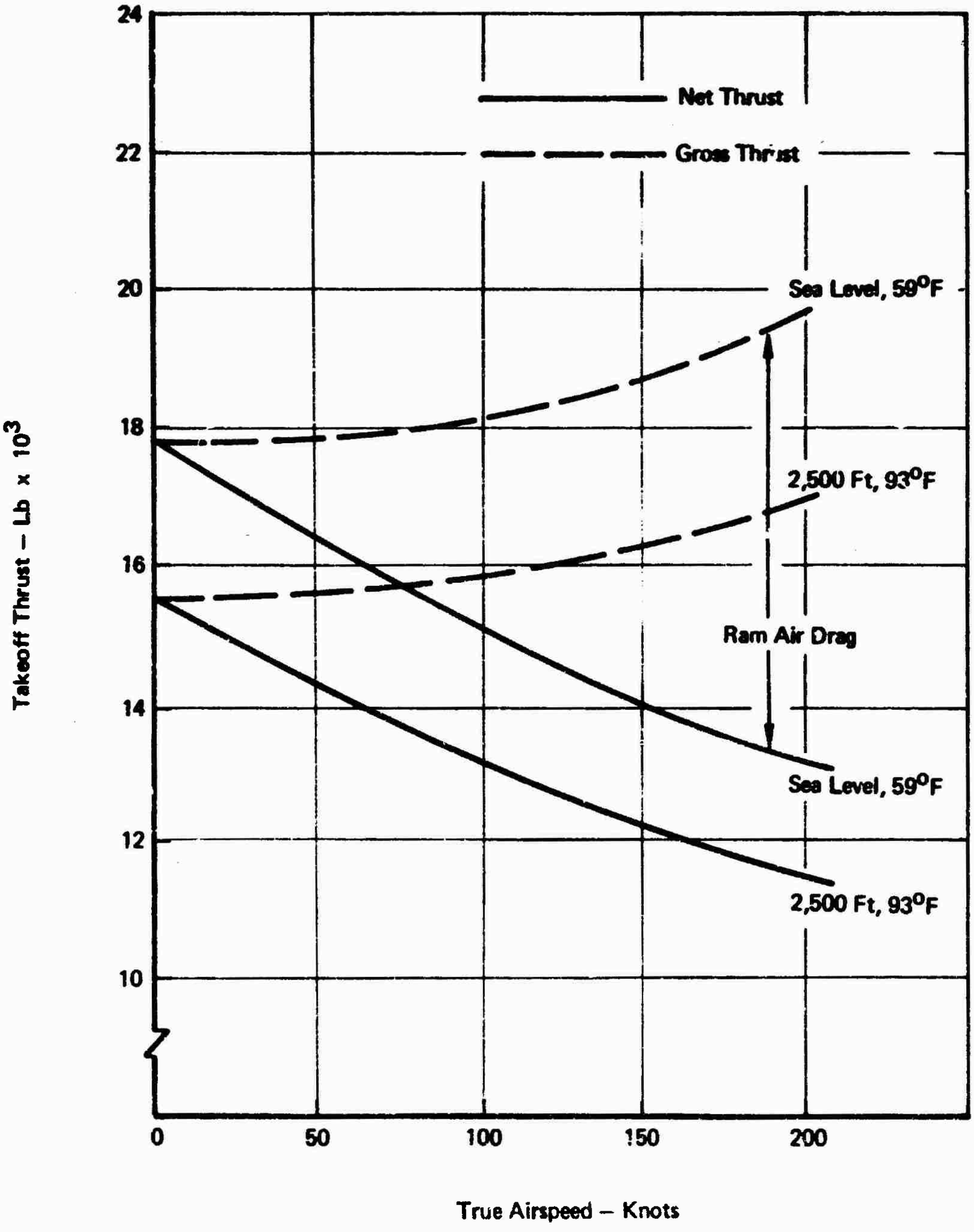


Figure 11: Engine Takeoff Thrust – .828 Scale Allison PD 351-2

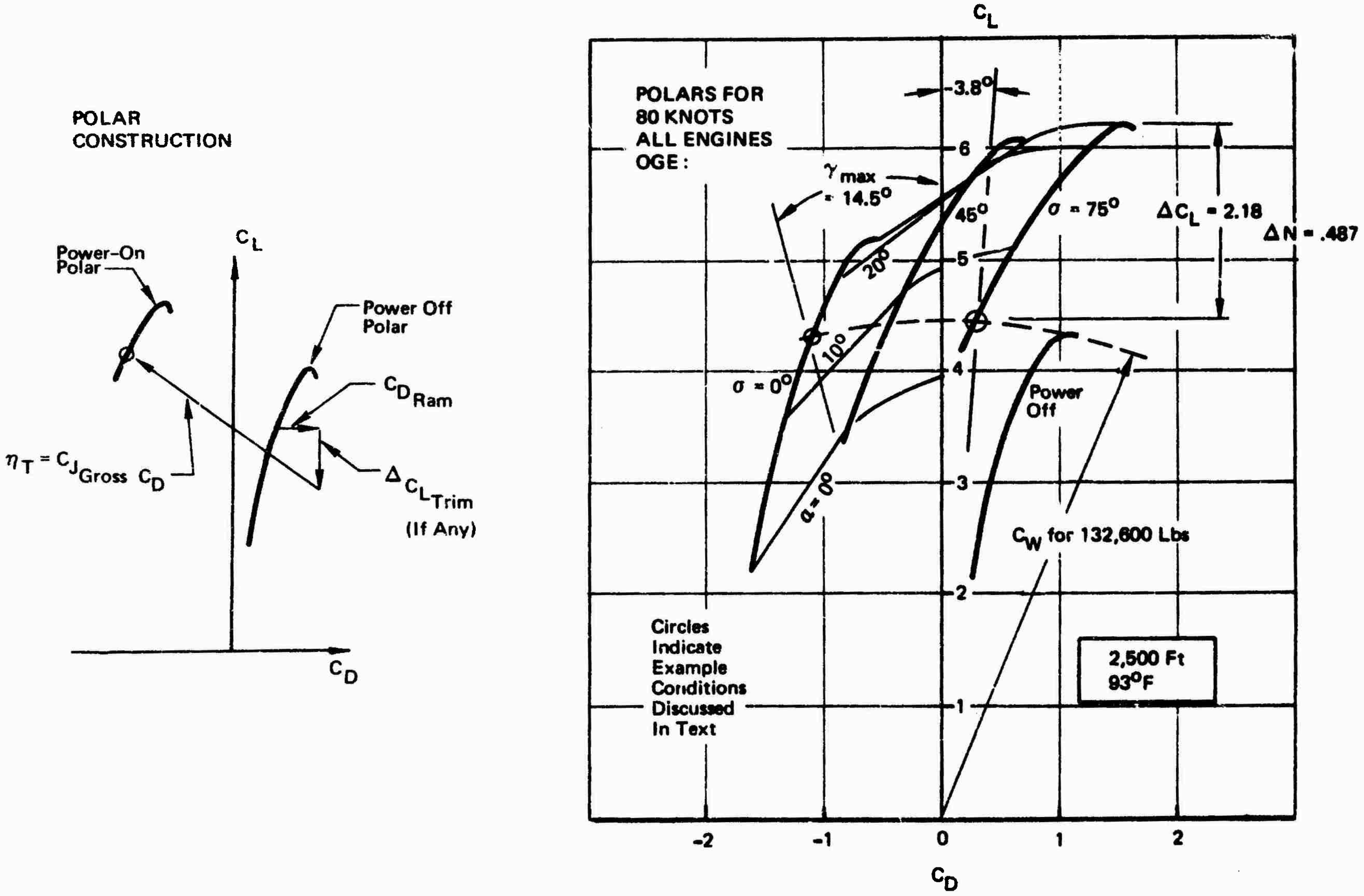


Figure 12: Powered Lift Force Polars

4.3 Speeds

Speeds are most conveniently discussed in the format used in NASA TN D-5594 (Reference 2). Angle of climb is plotted against speed for the configurations and power settings of interest. "g" margins, etc., are then superposed. Figures 13 through 16 show these data for the 953-801 airplane at 132,600 pounds, at 2500 feet, 93°F. Only the takeoff power setting is shown, but the whole range of available σ's are given. Figures 13 and 14 correspond to the engine-out condition, for determination of "normal" STOL performance, in free air and in ground effect. Figures 15 and 16 present the all engines operating data, for determination of "assault" performance.

4.3.1 Reference Minimum Speeds

V_{min} can be read or interpolated on the free air charts (Figures 13 and 15) as the extreme left end of the curve for the appropriate value of σ.

V_{mlo} is the point at which the climb gradient curve at the appropriate σ crosses the $\gamma = 0$ axis, provided that this point is not at a lower speed than V_{mca}. Here, V_{mca} does not even appear on the charts, because it is below V_{min} in every case.

V_{mtd} is here determined by stall in ground effect, since stall in ground effect occurs at the body attitude limit, and the descent angle provides additional clearance.

Table III summarizes these values, and also lists minimum control speeds.

Table III

Reference Minimum Speeds (Knots)

Condition	σ	V_{min}	V_{mlo}	V_{mtd}
Normal Takeoff	30^o	71.5	80.9	---
Assault Takeoff	30^o	67.0	70.0	---
Normal Landing	65^o	70.0	---	74.0
Assault Landing	75^o	62.0	---	66.0

Minimum Control Speeds

Air (V_{mca})	66.0 knots	(Roll, $\sigma = 75^o$)
Ground (V_{mcg})	68.5 knots	(Yaw, $\sigma = 30^o$)

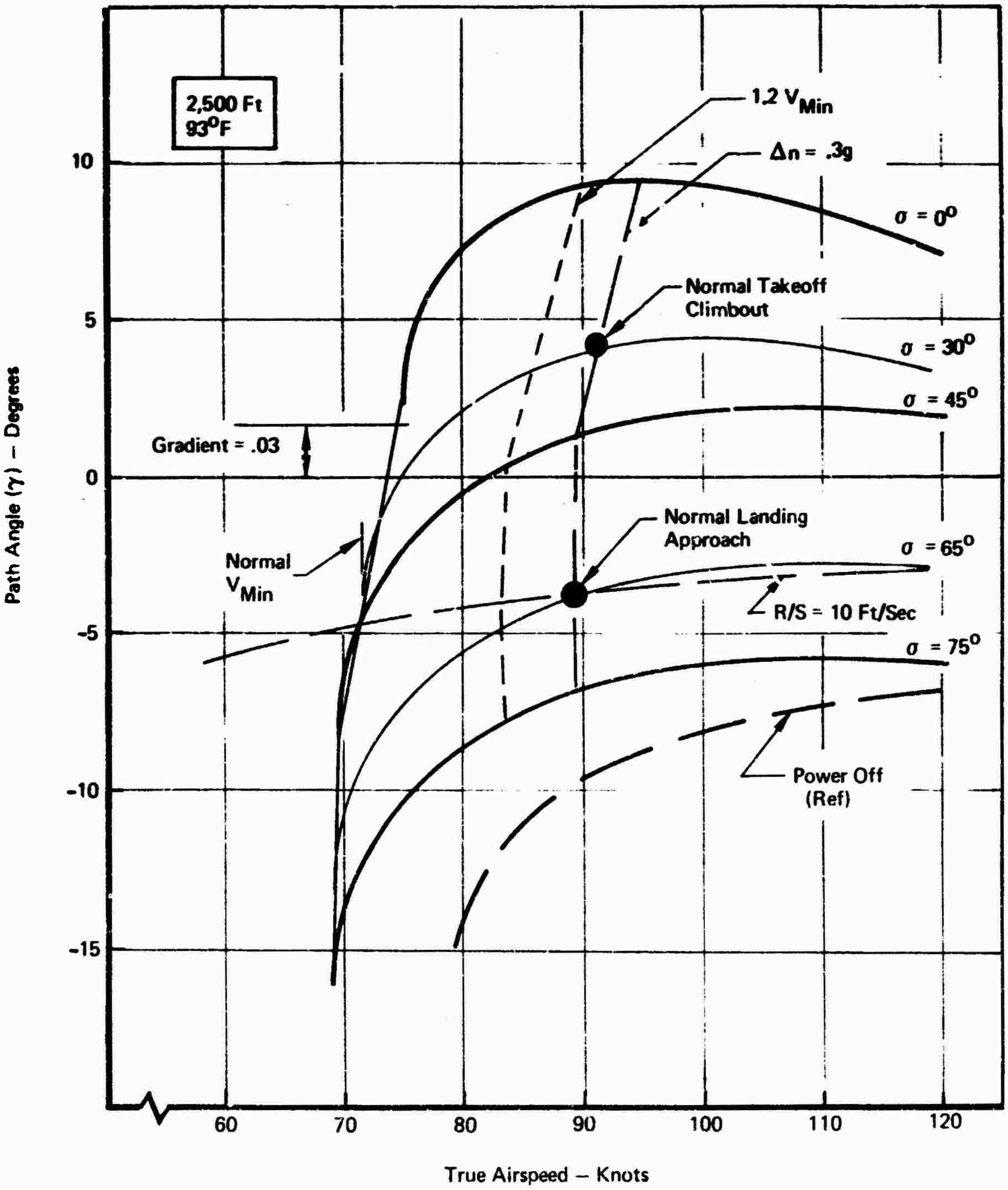


Figure 13: Operational Envelope - Engine Out, OGE

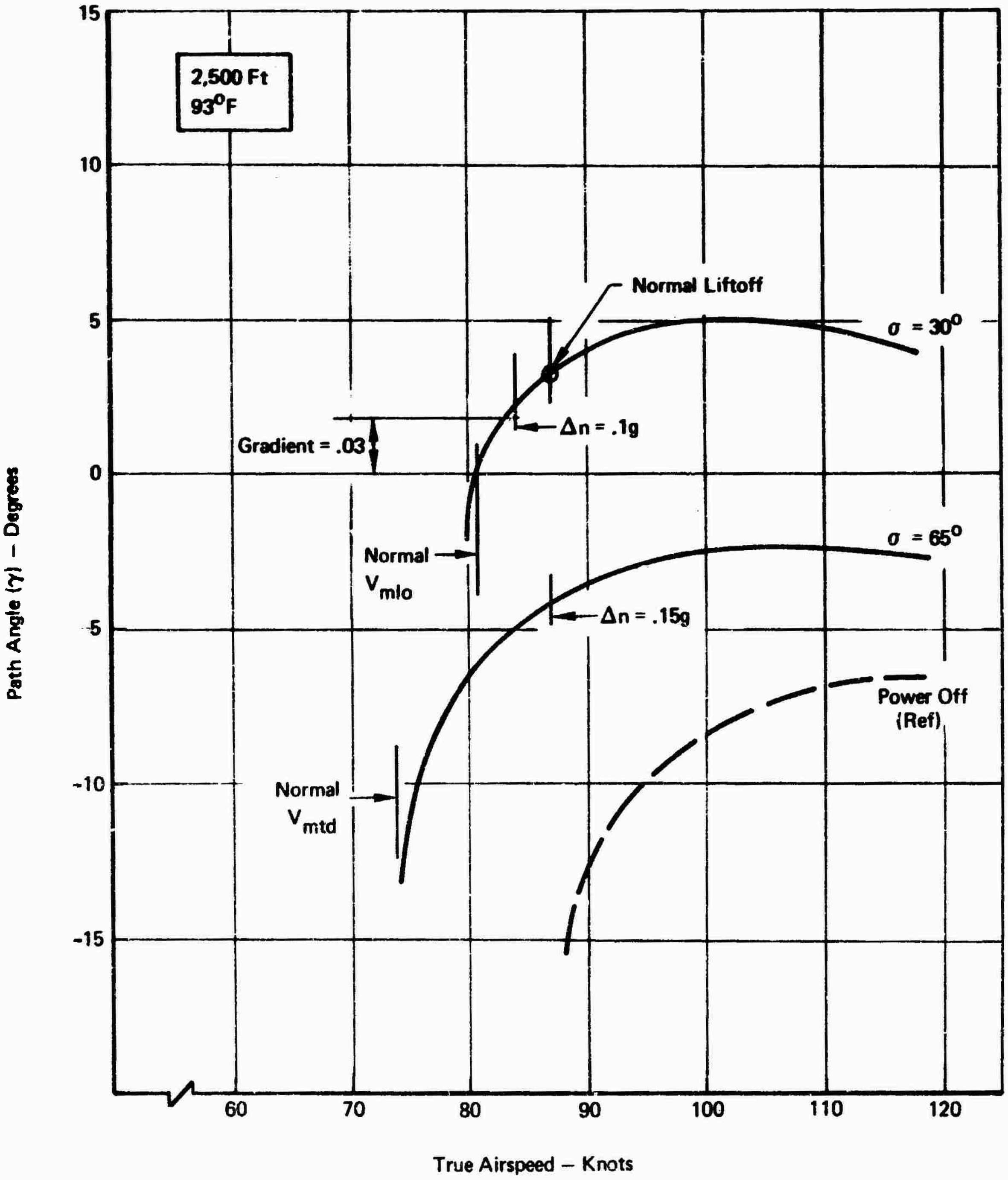


Figure 14: Operation Envelope - Engine Out, IGE

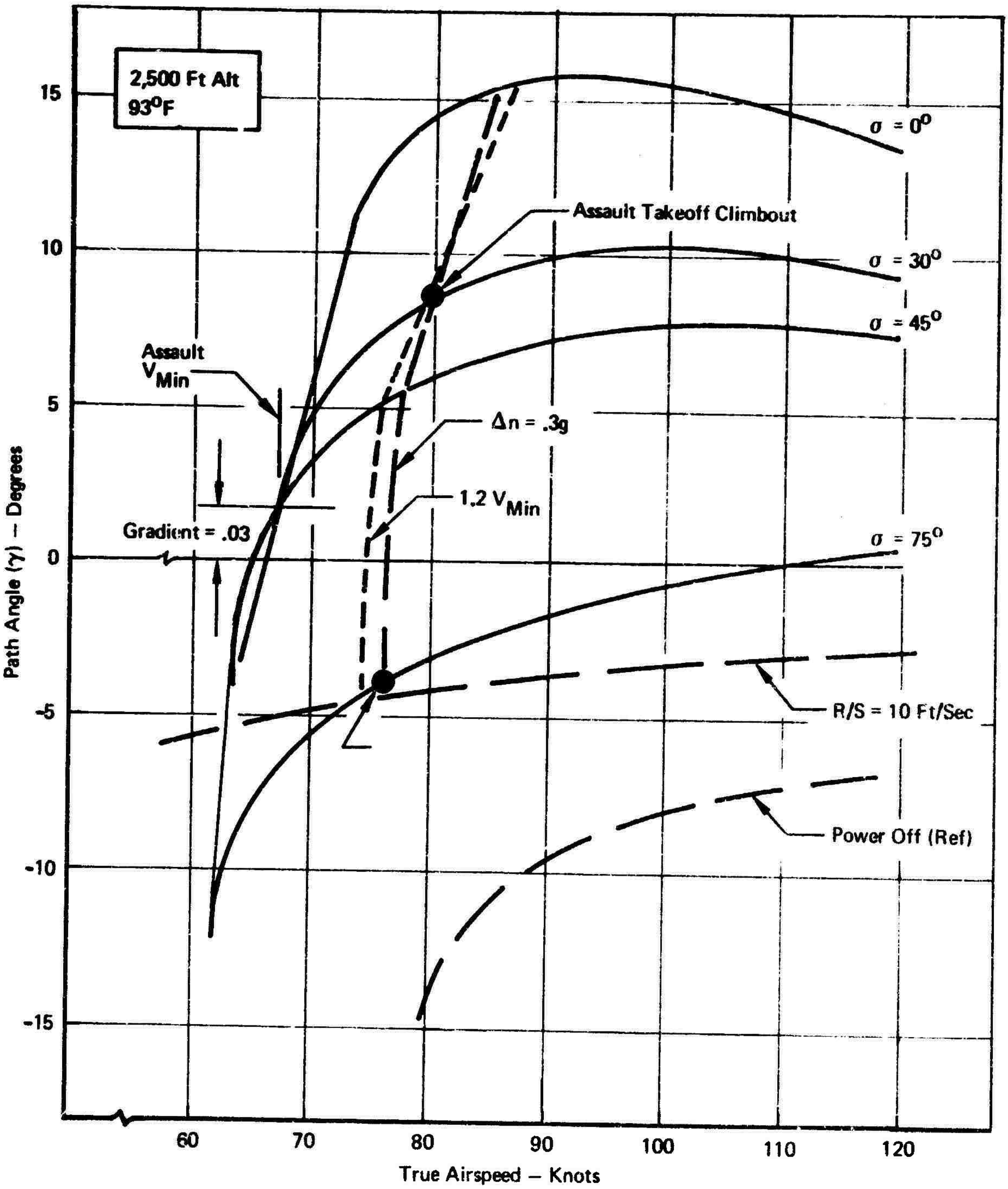


Figure 15: Operational Envelope – All Engines, OGE

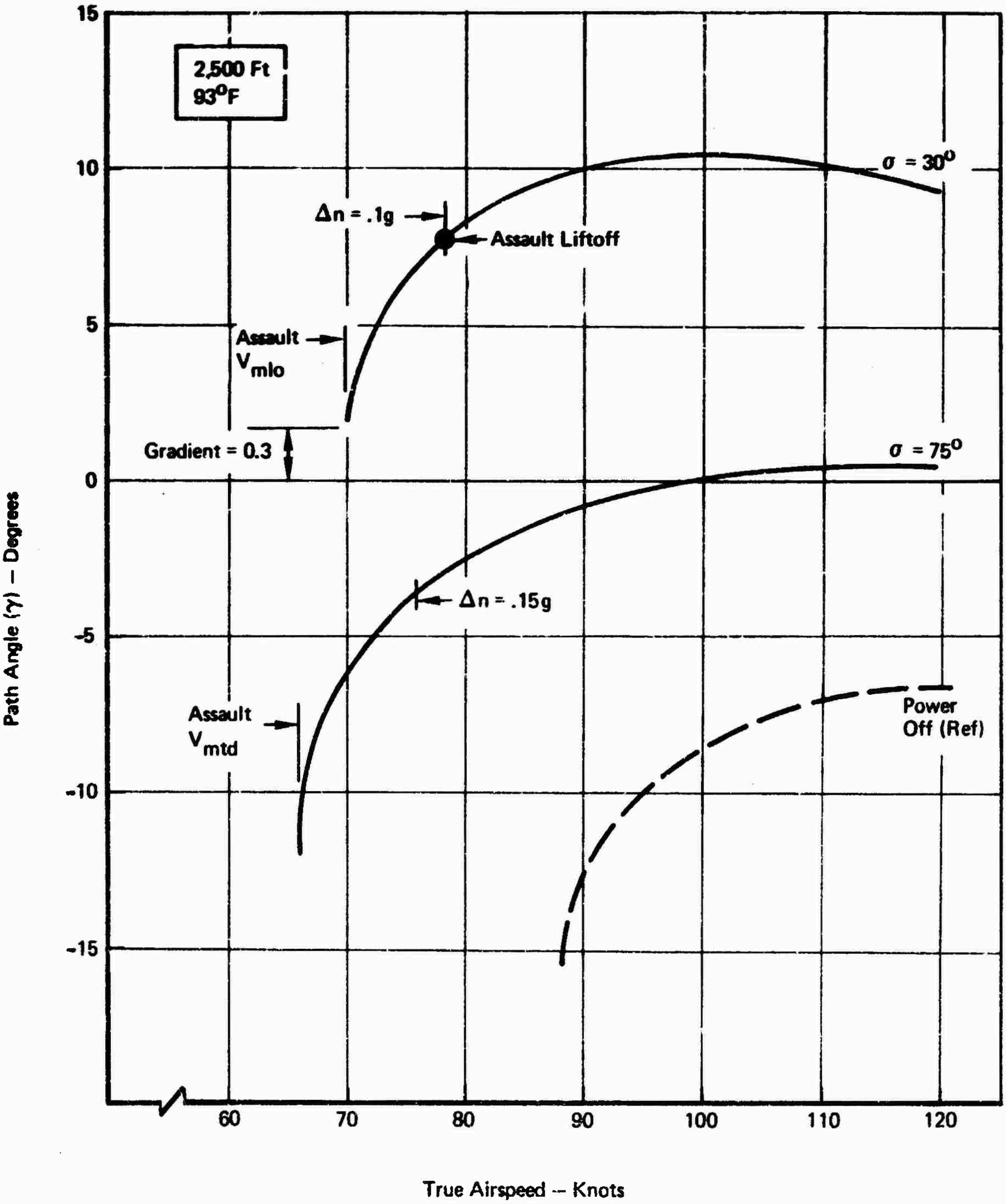


Figure 16 : Operational Envelope – All Engines, IGE

4.3.2 Operating Speeds

Normal Takeoff

V_{LO}: $1.08 \times V_{mlo} = 87.3$ knots

.1g Δn IGE → 84 knots

3% gradient IGE → 82 knots

$1.1 \times V_{min} = 78.9$ knots

$$\boxed{V_{LO} = 87.3 \text{ knots}}$$

V_{CO}: $1.2\ V_{min} = 86$ knots

.3g Δn OGE → 91 knots

3% gradient OGE → 78 knots

$$\boxed{V_{CO} = 91.0 \text{ knots}}$$

(Note: In this case, V_{CO} does not restrict speed or flap setting, and so does not affect field length.)

Assault Takeoff

V_{LO}: $1.08 \times V_{mlo} = 75.6$ knots

.1g Δn IGE → 78.5 knots

3% gradient IGE → 70 knots

$$\boxed{V_{LO} = 78.5 \text{ knots}}$$

V_{CO}: $1.2\ V_{min} = 80.5$ knots

.3g Δn OGE → 80 knots

3% gradient OGE → 67 knots

$$\boxed{V_{CO} = 80.5 \text{ knots}}$$

(Note: In this case, V_{CO} does not restrict speed or flap setting, and so does not affect field length.)

Normal Landing

V_{TH}: $1.2\ V_{min} = 84$ knots

.3g Δn OGE → 89.5 knots

$1.1\ V_{mca} = 72.5$ knots

$$\boxed{V_{TH} = 89.5 \text{ knots}}$$

(10 ft/sec rate of sink limit requires $\gamma = -3.8°$, which determined $\sigma = 65°$.)

V_{TD}: $1.1\ V_{mtd} = 81.5$ knots

.15g Δn IGE → 86.7 knots

$V_{TH} = 89.5$

$$\boxed{V_{TD} = 89.5 \text{ knots}}$$

Assault Landing

V_{TH}: $1.2\ V_{min} = 74.5$ knots

.3g Δn OGE → 76.3 knots

(Reduces rate of sink to 9 feet per second at $\sigma = 75°$.)

$$\boxed{V_{TH} = 76.3 \text{ knots}}$$

V_{TD}: $1.1\ V_{mtd} = 72.6$ knots

.15g Δn IGE → 76 knots

$V_{TH} = 76.3$ knots

$$\boxed{V_{TD} = 76.3 \text{ knots}}$$

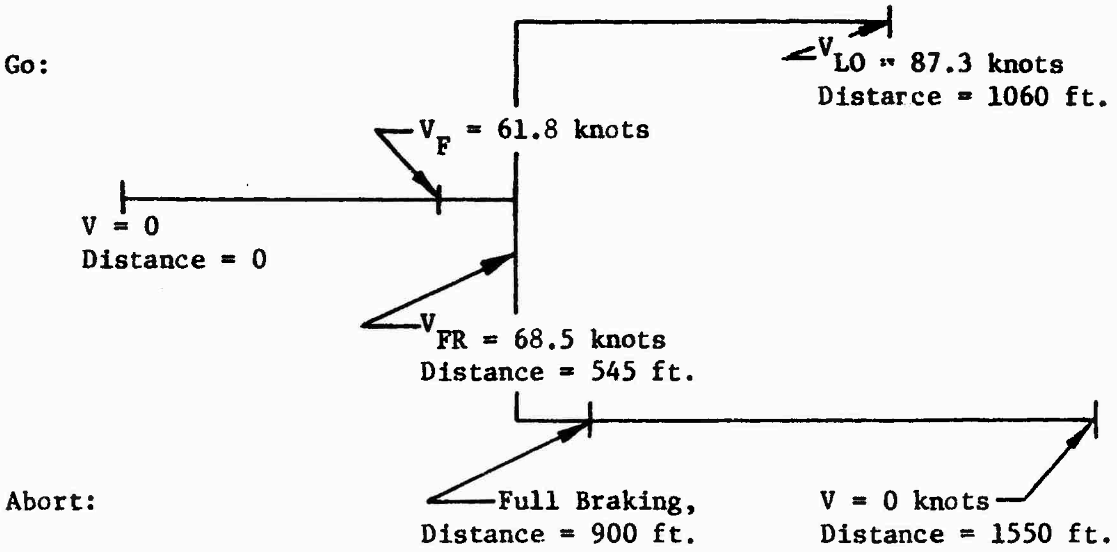
4.4 Field Lengths

Normal Takeoff

The takeoff procedure used here is as follows: At the start of roll, σ is set to 0°. At V_{FR}, σ is rotated to 30°, and the acceleration continues until the airplane lifts off.

$V_{FR} = 68.5$ knots, set by V_{mcg}. Therefore, the critical field length is not balanced.

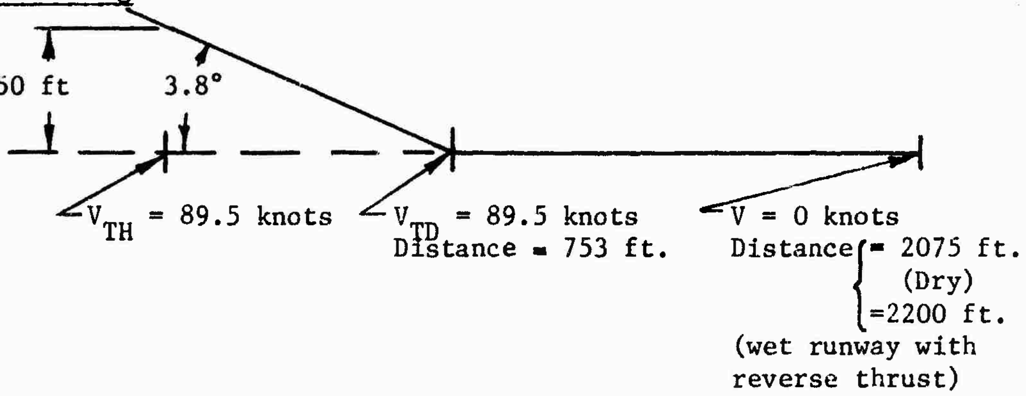
The speeds and distances are as follows:



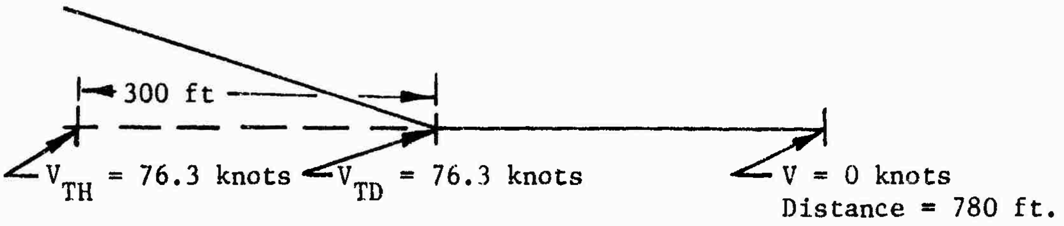
Assault Takeoff

Distance - 740 feet, at V_{LO} = 78.5 knots.

Normal Landing



Assault Landing



4.5 Concluding Remarks

The field lengths given in the preceding section do not match the values to which the 953-801 airplane was designed. This was to be expected, since the "STAI Baseline" rules were used to obtain the design values.

The "normal" takeoff field length was reduced from 2000 feet to 1550 feet, because the climb to 50 feet was eliminated.

The landing distance increased from 1700 feet to 2075 feet because of the increase in threshold speed due to the .3g maneuver requirement (versus .2g in the STAI), despite credit for a slightly higher braking coefficient.

Airplanes designed to the proposed rules will tend to have bigger wings and less installed thrust than for the STAI. The authors consider the shift in emphasis prudent, since landing tends to be a more difficult phase of flight.

APPENDIX

PERFORMANCE CALCULATION PROCEDURES

1. Introduction

This appendix contains a description of the methods used to determine the takeoff and landing performance of the 953-813. There were some differences between the AFFDL rules for updating the STAI baseline configuration and those recommended here in Volume III. The sizing of the 953-813 and all performance shown in Volume I was determined in accordance with AFFDL rules.

2. Normal Takeoff

Normal takeoff distances were based on the total distance to accelerate on four engines to the critical powerplant failure speed, experience a critical powerplant failure, then continue the takeoff with the remaining three powerplants, or stop in the remaining distance (Figure 3).

Forces acting on the airplane during ground roll are shown in Figure 17. The aerodynamic coefficients (C_L and C_D) contain the vertical and horizontal components of the gross thrust vector. During ground roll, C_L and C_D were obtained from the drag polar at $\alpha_{body} = 0°$ as a function of C_J. Thrust vector was set at 7° (to clear the flap trailing edge) from brake release to V_R, then rotated to the maximum angle that would provide a climb angle of 3° with the critical engine inoperative.

The acceleration was obtained from the following expression:

$$a = \frac{C_D qS + D_{ram} + \mu\ (W - C_L qS)}{W/g}$$

where: a = acceleration

$g = 32.2\ \mathrm{ft/sec}^2$

q = dynamic pressure

S = wing area

W = airplane weight

D_{ram} = ram drag

$\mu = .1$ (rolling friction coefficient)

Note: C_L and C_D include propulsive forces.

The distance for segments A, B, and C were obtained from the expression:

$$s = \int_{V_i}^{V_f} \frac{VdV}{a}$$

where: s = distance to accelerate from V_i to V_f

V_i = initial velocity

V_f = final velocity

The distance required to stop (Segment E) was also obtained from Equations (1) and (2). The acceleration term to be integrated is then negative. However, since the limits of integration go from large velocity to zero velocity, the stopping distance is positive. When stopping, thrust was set at idle, the friction coefficient was increased to $\mu = .3$, the lift was decreased due to spoilers, and the drag was increased due to spoilers.

2.1 Speed Definitions

Minimum Flight Speed

V_{min} - The lowest speed at which the aircraft is controllable in steady 1g flight out of ground effect:

(1) With powerplants supplying power output levels for normal operation in the applicable flight configuration.

(2) At appropriate weight, elevation, and temperature for which the minimum speed was used.

(3) At the most favorable center of gravity within the allowable limits.

(4) With the critical powerplant component supplying propulsion inoperative (except for "assault").

Minimum Liftoff Speed

V_{mlo} - The lowest speed at which the airplane can lift off the ground and continue the takeoff.

(1) With powerplants supplying power output levels for takeoff.

(2) At the appropriate weight, elevation and temperature for which the minimum speed was used.

(3) At the most unfavorable center of gravity within the allowable limits.

(4) With the critical powerplant component supplying propulsion and lift inoperative. (Except for "assault".)

V_{mcg} - Ground minimum control speed. The minimum speed at which controllability by aerodynamic controls and nose gear steering is adequate to permit proceeding safely with the takeoff using average piloting skill, when the critical powerplant is suddenly made inoperative.

V_F - Critical powerplant failure speed.

V_{FR} - Critical powerplant failure recognition speed.

2.2 Takeoff Speed Limitations

V_F - Critical powerplant failure speed $\geq V_{mcg}$.

V_R - Takeoff rotation speed. V_R is the speed at which rotation was initiated. V_R was $\geq V_{FR}$

V_{LO} - The liftoff speed.

$\geq$ 1.05 V_{mlo} with the critical powerplant inoperative.

$\geq$ The speed providing 1.1g normal acceleration with the critical powerplant inoperative, in ground effect.

V_{co} - The climbout speed was assumed equal to the liftoff speed and in all cases:

$V_{co} \geq 1.1 V_{min}$ with the critical powerplant inoperative.

$\geq$ The speed providing 1.3g normal acceleration in free air with the critical engine inoperative.

3. Assault Takeoff

Assault takeoff distances were based on the distance to accelerate on four engines to liftoff (Figure 18). Thrust was set at 7° from brake release to rotation and then vectored to the angle that would provide a 3° climbout with all four engines operating. Liftoff and climbout speed and maneuver margins were the same as for normal takeoffs except they were determined with all engines operating:

$V_{LO} \geq 1.05\ V_{mlo}$

$\geq 1.10g$ normal acceleration

$V_{CO} \geq 1.10\ V_{min}$

$\geq 1.30g$ normal acceleration.

4. Normal Landing

Normal landing distances were based on the total distance to stop from a threshold height of 50 feet. The landing distance was determined in three segments as shown on Figure 19.

Air Distance was based on (1) crossing the threshold at a steady 10 fps rate of sink, (2) no flare and (3) touching down at the threshold rate of sink.

$$\text{Air Distance} = \frac{50\ \text{ft}}{\tan \gamma}$$

where: $\tan \gamma \approx \sin \gamma$

$$\sin \gamma = \frac{10\ \text{fps}}{V_{TH}}$$

V_{TH} = threshold speed, fps

Transition Distance - Two seconds were allowed to lower the nose, deploy spoilers and apply brakes.

$$\text{Transition Distance} = 2\ V_{TH}\ (\text{fps})$$

Braking Distance - The distance required to stop was determined from the basic distance equation:

$$\text{Braking Distance} = \int_{V_B}^{0} \frac{V dV}{a}$$

The forces acting on the airplane during braking are shown on Figure 22.

$$a = -\frac{D + D_{ram} + T_{rev}\ (\cos \sigma_{rev}) + \mu\ (W - L + T_{rev}\ \sin \sigma_{rev})}{W/g}$$

where: L = aerodynamic lift with spoilers deployed

D = aerodynamic drag with spoilers deployed

D_{ram} = engine ram drag

T_{rev} = reverse thrust (two engines)

σ_{rev} = reverse thrust vector angle

W = gross weight

μ = .3

Minimum Touchdown Speed Definition

V_{mtd} - The lowest speed at which the airplane can touch down:

(1) With powerplants applying power output levels for normal operation at touchdown.

(2) At the appropriate weight, elevation, and temperature for which the minimum speed was used.

(3) At the most unfavorable center of gravity within the allowable limits.

(4) With the critical powerplant component supplying propulsion and lift inoperative. (Except for "assault".)

Landing Speed Limitations

The normal threshold speeds were selected to provide the following margins with the critical engine inoperative:

$V_{TH} \geq$ 1.1 minimum flight speed, V_{min}

$\geq$ The speed providing a 1.3g normal acceleration in free air

$\geq$ 1.1 minimum touchdown speed, V_{mtd}

$\geq$ The speed providing a 1.15g normal acceleration in ground effect.

Landing vector angles were selected to provide waveoff capability from 100 feet with the critical engine inoperative.

5. Assault Landing

Assault landing distances consist of a 300 ft. air distance, a 2 second transition and a braking segment utilizing maximum braking and maximum four engine thrust reversal (Figure 21).

Equations used for assault transition and stopping distances were the same as those for normal landing.

Assault Landing Speeds

The assault landing speeds were selected to provide the same margins as the normal landing speeds. However, assault landing margins were determined with all engines operating.

$V_{TH} \geq$ 1.1 minimum flight speed, V_{min}

$\geq$ The speed providing a 1.3g normal acceleration in free air

$\geq$ 1.1 minimum touchdown speed.

$\geq$ The speed providing a 1.15g normal acceleration in ground effect.

Thrust vector angles were selected to provide waveoff from 50 ft. with all engines operating.

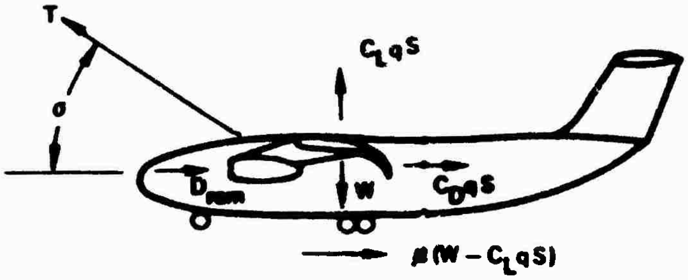


Figure 17: Ground Roll Forces

Figure 18: Assault Takeoff Distance

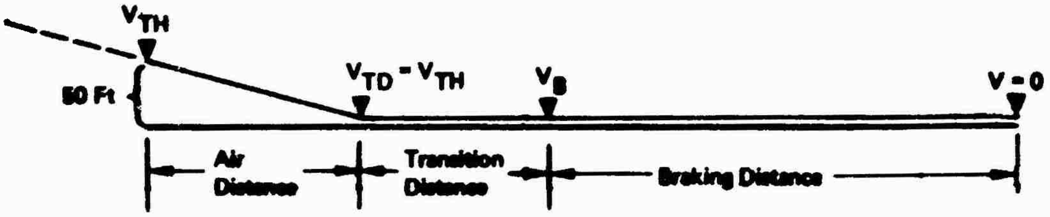


Figure 19: Normal Landing Distance

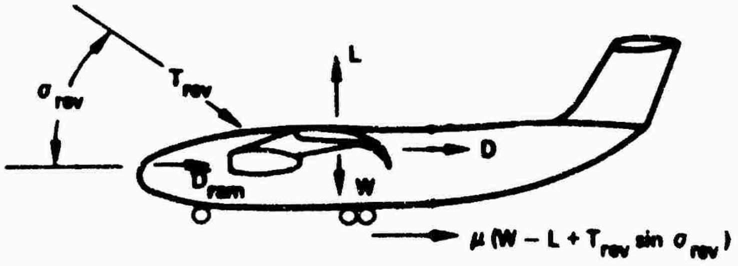


Figure 20: Forces During Braking

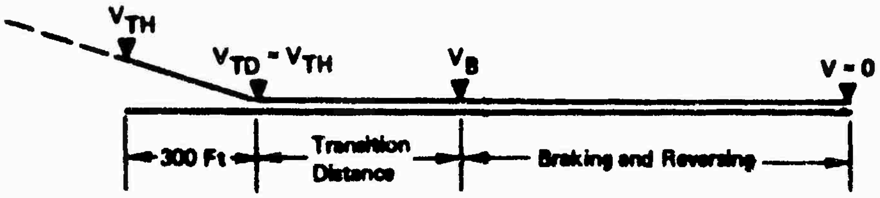


Figure 21: Assault Landing Distance

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