ASD-TR-68-56

AIRCRAFT BRAKE ENERGY ANALYSIS PROCEDURES

DALE E. CREECH

TECHNICAL REPORT ASD-TR-68-56

OCTOBER 1968

DEPUTY FOR ENGINEERING
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

DISCLAIMER NOTICE

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This document has been approved for public release and sale; its distribution is unlimited.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

200 - March 1969 - CO455 - 70-1554

ASD-TR-68-56

AIRCRAFT BRAKE ENERGY ANALYSIS PROCEDURES

DALE E. CREECH

FOREWORD

The research described herein was accomplished through review of various aircraft braking parameters during the time period of 1955 to 1968. Work was a accomplished under System No. 139A. The author served as project engineer.

The report was submitted by the author on 12 August 1968.

The author wishes to acknowledge the assistance of personnel of the Landing Gear and Mechanical Equipment Division, Directorate of Airframe Subsystems Engineering, and of the Digital Computation Division, Directorate of Computation Services, ASD, for significant contributions to the work presented herein.

This technical report has been reviewed and is approved.

Wm A Hamilton
WM A HAMILTON
Chief, Landing Gear & Mechanical
Equipment Division
Directorate of Airframe Subsystems
Engineering

ABSTRACT

This report describes a standardized method for analyzing and calculating aircraft brake energy requirements. The method is an adaptation of method II of MIL-W-5013 and requires exact inputs readily adapted to computer use. These methods have been used in an analysis of the C-5A, F-111, and AMSA aircraft brake energy requirements. Programming the equations into a computer gave very satisfactory results. The methods can be used manually or by a computer to determine the braking energy requirements of any aircraft.

TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

SECTION I
INTRODUCTION

The problems encountered in designing landing gear systems for aircraft are many and complex, and their solutions are both difficult and time consuming. The military brake specification, MIL-W-5013, gives two methods for determining the necessary brake energies -- Method I, which involves a simplified equation that provides a determination of the approximate brake energies involved; and Method II, which gives more precise values by considering all the known energy absorbers and additives associated with the process of landing and stopping an aircraft. Aircraft manufacturers normally use Method II in making their analysis. Over the past several years, most manufacturers have computerized many of the problems associated with this analysis because of time and manpower considerations.

The aircraft manufacturers have little or no trouble in analyzing the braking problems, because they have available the equipment and data needed to make the computations. The Air Force monitoring engineer, however, finds it both impractical and impossible to analyze the situation because of the time required and lack of appropriate data. While existing military specifications require the manufacturers to submit specific analysis data, they do not require certain basic data needed as inputs for these calculations. In view of this problem, this report presents analysis procedures and a listing of standard data requirements needed for making a braking analysis by Method II. With this information, the engineer can make adequate calculations to verify the contractor's analysis of braking energy, stopping distance, velocity at touchdown, velocity at brake application, and rate of sink at touchdown.

To facilitate this analysis, data requirements as set forth herein should be established in the official specification so that the engineer can make an adequate analysis. Then for the first time, the monitoring engineer will have the necessary tools at hand to readily determine braking energies and stopping distances.

SECTION II

DATA REQUIREMENTS

1. DATA REQUIREMENTS OF MIL-W-5013

Military Specification MIL-W-5013, Method II, provides a method of determining braking capacity by mathematical and graphical analysis based on principles of aerodynamic motion. The following are quoted from the specification as items to be considered:

a. Actual energy of the mass of the aircraft at instant of touchdown.

b. An integration of the kinetic energy added to the aircraft by thrust of the aircraft's propulsion system during the stop.

c. An integration of kinetic energy absorbed by aerodynamic drag of the aircraft during the stop,

d. An integration of the kinetic energy absorbed by auxiliary braking effort, such as propeller reverse thrust, deceleration parachutes, or jet reverse thrust during the applicable portion of the stop in accordance with table I.

e. An integration of the kinetic energy to be absorbed by wheel brakes during the stop.

f. Effect of wing lift in reducing the wheel load during the stop, thereby decreasing the torque which can be developed without skidding the tires.

g. Distribution of load and brake capacity among the various wheels.

h. Total stopping distance.

i. Static force available for holding aircraft stationary while running up engines.

j. Appropriate ground winds, airport altitudes, and ambient atmospheric conditions.

k. Landing speed for aircraft shall not be less than aircraft design landing speed as defined in 6.3.5.

m. Brake retarding forces versus time curves and brake retarding forces versus speed curves for each design condition.

n. A complete static and dynamic analysis shall be made by the aircraft manufacturer of the main and auxiliary wheel loads. From this analysis, a loading spectrum shall be prepared and submitted to enable design and testing of the wheels.

2. REQUIREMENTS FOR DETERMINING BRAKING CAPACITY

This report presents a method of computing braking capacity that is more definitive than that presented in MIL-W-5013 and which Air Force engineers can use to check the contractor's calibrations. For these computations, we need inputs that are different from the factors listed in MIL-W-5013. For example, instead of the energy of the mass at touchdown (Item a above) we need data on the actual gross weight, the c.g. position, and the touchdown velocity to determine the energy at touchdown. Instead of Item b, we need the thrust of the engines versus time and velocity to compute the energy added to or subtracted from the aircraft from a time one second prior to touchdown until it comes to a complete stop. All of the factors can be computed in this way and compared with values submitted by the contractor. For these computations, the following data is needed and should be required from the contractor:

a. Time. The time, starting one second prior to touchdown for landings and one second prior to brake application for rejected takeoffs in increments of 0.25 second.

b. Velocity. The speed listed in feet/second as follows:

(1) Touchdown - Unless otherwise designated, this velocity is $1.1\ V_{spa}$, (1.10% of the stall velocity with power on in the landing configuration).

(2) Rate of Descent - The vertical velocity during the approach on a 3° glide slope.

(3) Rate of Sink - The vertical velocity after flare and at the instant of touchdown; in calculating braking energies and stopping distances, use 4 ft/sec for all landings. (Note: 4 ft/sec is considered an average, but not the maximum sink rate required by military specifications.)

(4) Brake Application Velocity - Equal to 1.0 V_{spa} unless the brakes are applied earlier for higher performance.

c. Thrust. Thrust in pounds is required in at least 3 quantities: (1) gross thrust per engine versus velocity, (2) net thrust per engine versus velocity, and (3) net thrust for all engines versus velocity. Values should include the entire range of landing velocities. Values for net thrust in a direction parallel to the ground should be plotted versus time for the landing approach, touchdown, and roll out, as shown in the example (Figure 1). If the aircraft has reverse thrust capability, values should also be included for reverse thrust net force. If more than one configuration can be used for reverse thrust (i.e., 2 out of 4 engines), values for these conditions should also be given.

d. Coefficient of Aircraft Drag (C_D). Dimensionless units versus time are required for landing approach, touchdown and roll-out configurations, as shown in the example (Figure 2).

e. Dynamic Pressure (q). Pressure in lbs/ft^2, for all altitudes and outside air temperatures appropriate for the aircraft.

f. Effective Area (S_W). Units in square feet.

g. Coefficient of Lift (C_L). Dimensionless units versus time required, as shown in the example (Figure 3).

h. Deceleration Chute Drag (D_C). Deceleration force, given in pounds.

i. Deceleration Chute Drag Coefficient (C_{DC}). Dimensionless units plotted versus time.

j. Effective Deceleration Chute Area (S_C). Effective area of deceleration chute(s), in square feet.

k. Percentage of Load on Landing Gears. Percentages of weight versus time, as shown in example (Figure 4), for the main gear (P_M) and nose gear (P_N).

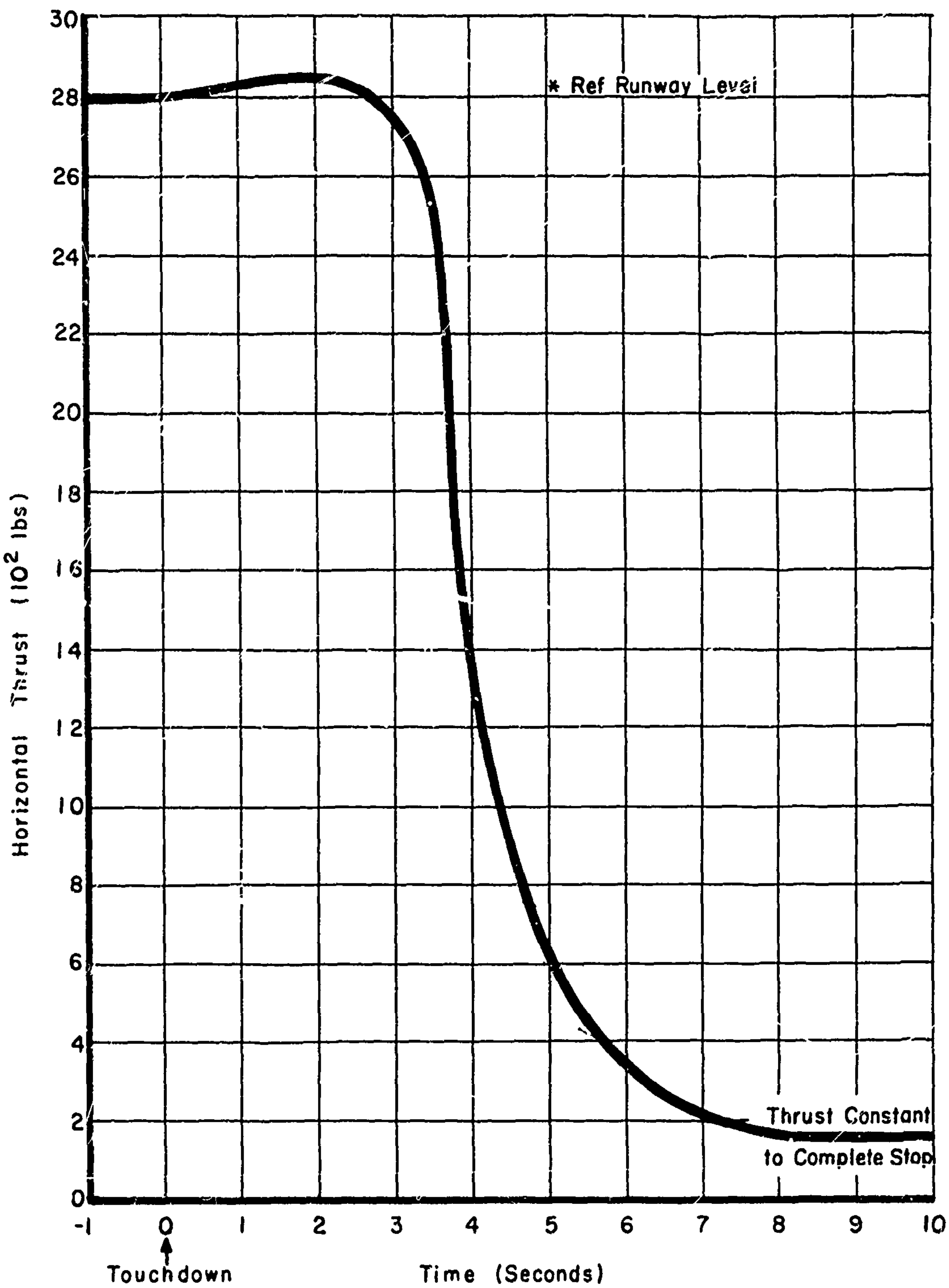


Figure 1. Sample Plot of Net Thrust Versus Time

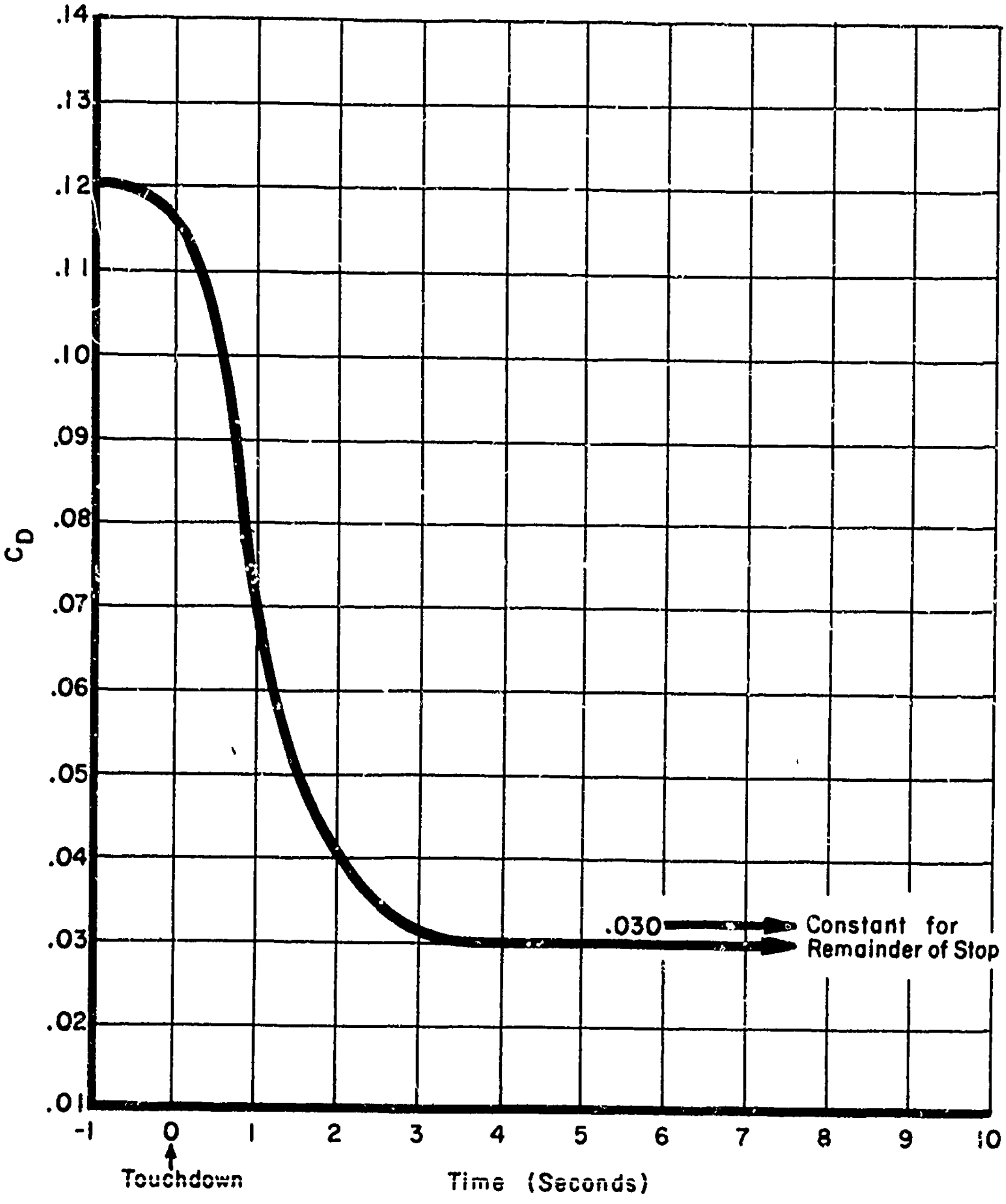


Figure 2. Sample Plot for Determining Coefficient of Drag Versus Time

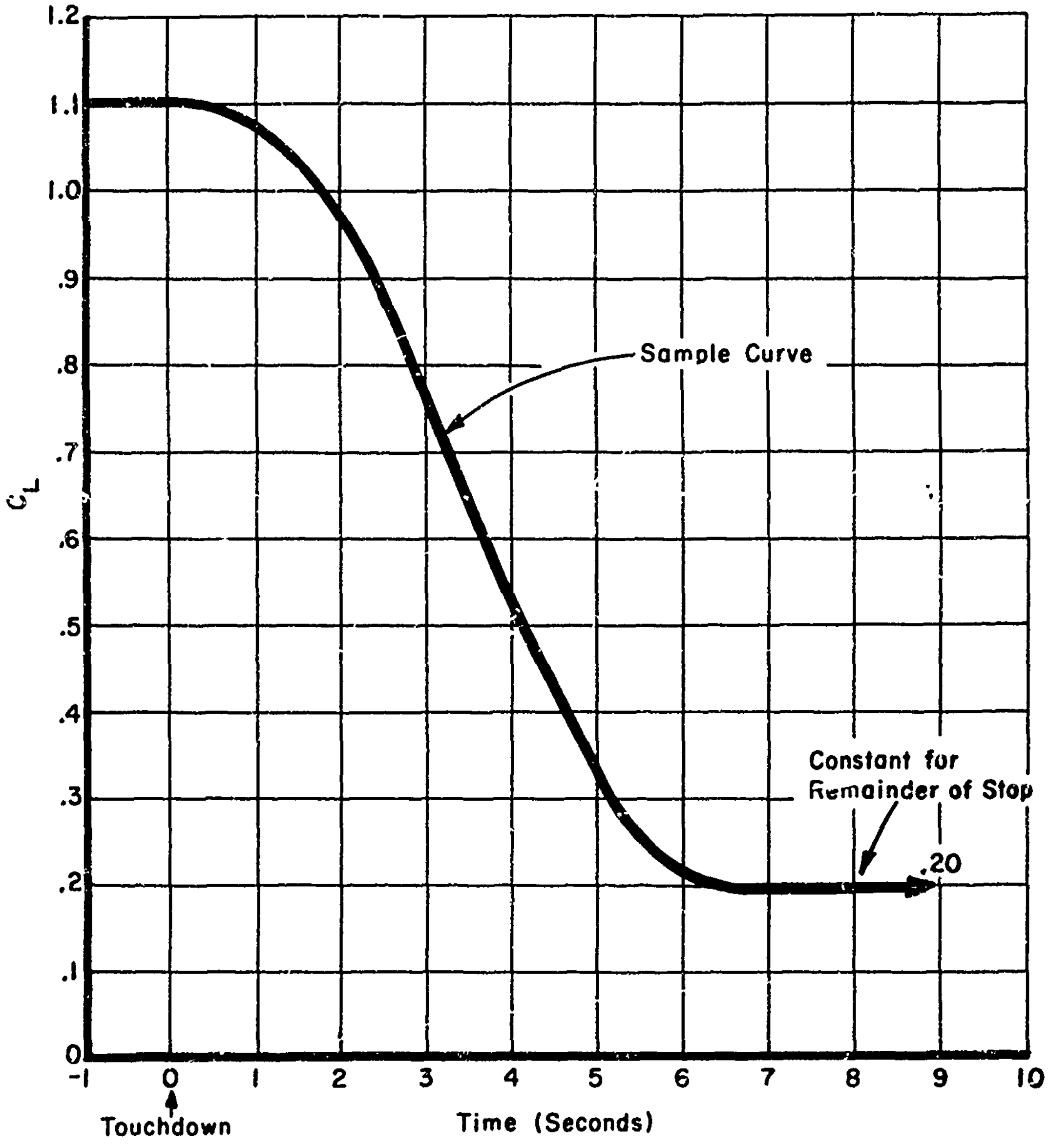


Figure 3. Sample Plot for Determining Coefficient of Lift Versus Time

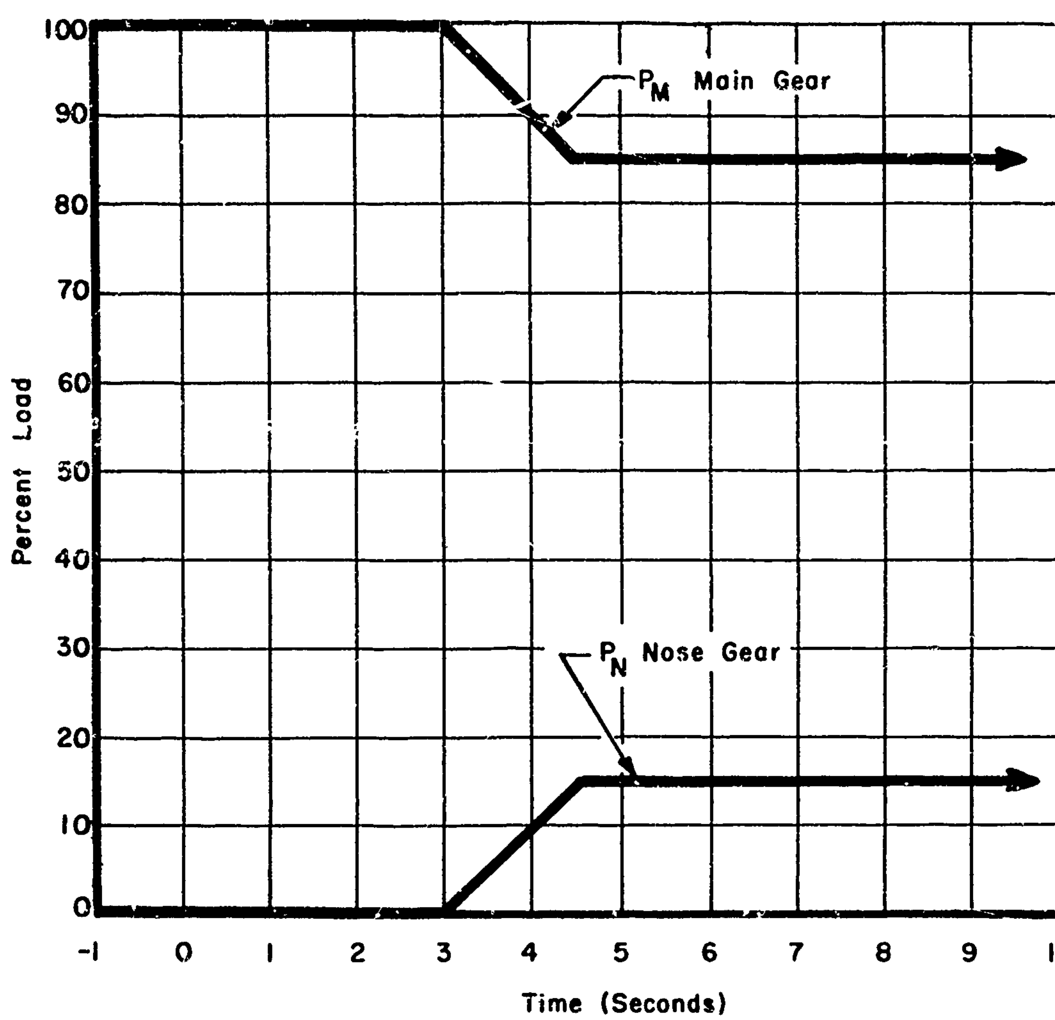


Figure 4. Sample Curves for Determining Percentage of Static Load on Main and Nose Gears Versus Time

3. LANDING VELOCITY CONSIDERATIONS

The landing speed of the aircraft is not defined in MIL-W-5013, (Par 1, Item k above). Here we will define landing speed positively as touchdown speed, which is equal to 1.1 V_{spa}, where V_{spa} is defined as the stall-speed-with-power-on landing configuration, per MIL-A-8860. The kinetic energy to be absorbed by the wheel brakes during stop is considered equal to 1.0 V_{spa}. If the velocity at brake application in a specific situation is greater than this value (due to operation of a specific aircraft), then the velocity should be increased accordingly.

Three basic conditions for which braking is required are considered in this report: normal landing, maximum gross weight landing, and rejected takeoff. These three conditions are described as follows:

a. Normal Landing

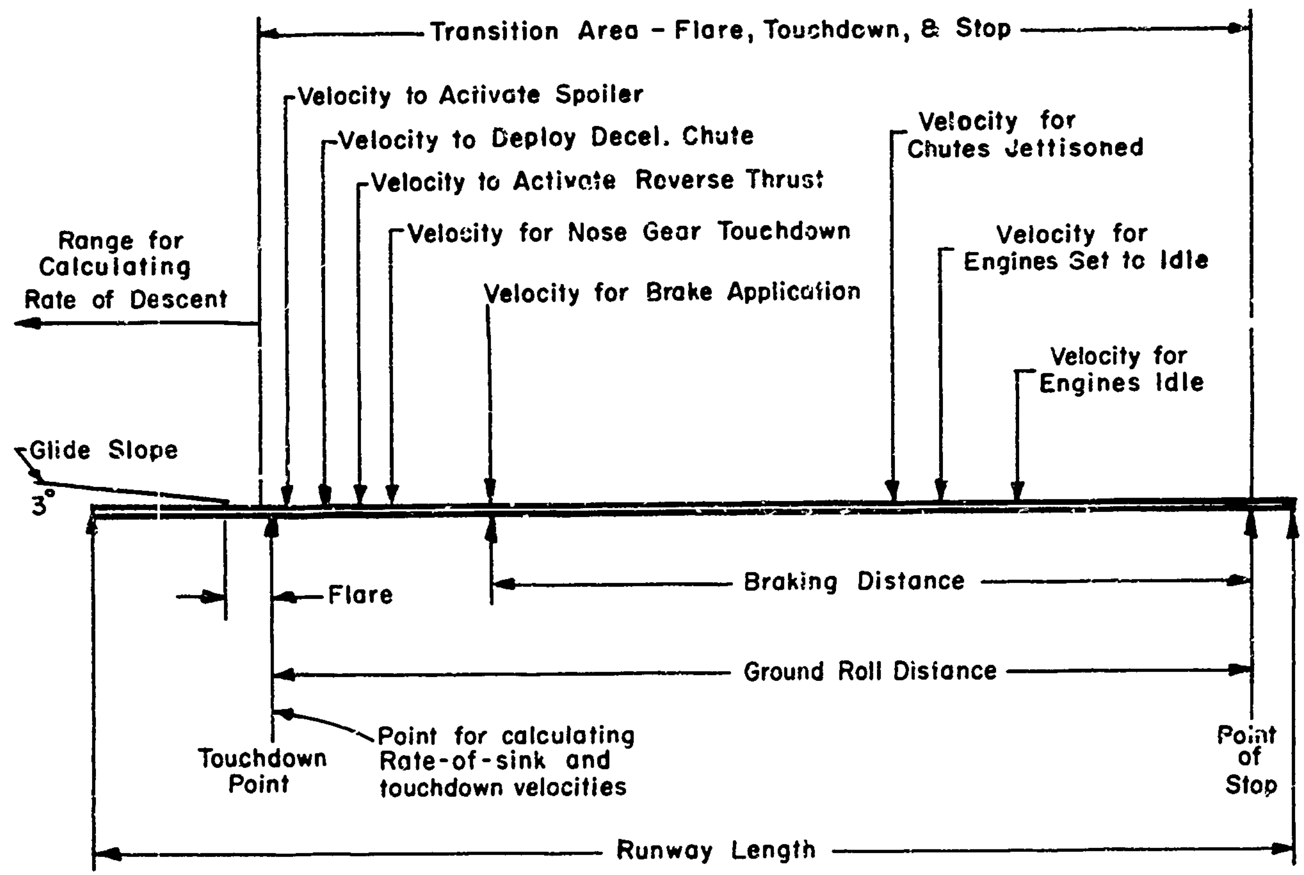
In a normal landing, the aircraft follows a 3° glide slope to point of touchdown and has a gross weight of "landplane landing design gross," as described in Reference 2. The rate of sink velocity, touchdown (forward) velocity, and brake application velocity are provided, as required by Section II. All changes in configuration for the transition area are shown in Figure 5; if additional changes are required after the brakes are applied, these must also be indicated.

b. Maximum Gross Weight Landing

Maximum gross weight landing conditions consist of an aircraft following a 3° glide slope to point of touchdown with an aircraft gross weight of "maximum landing gross," as described in Reference 2. All other factors are the same as for the normal landing situation.

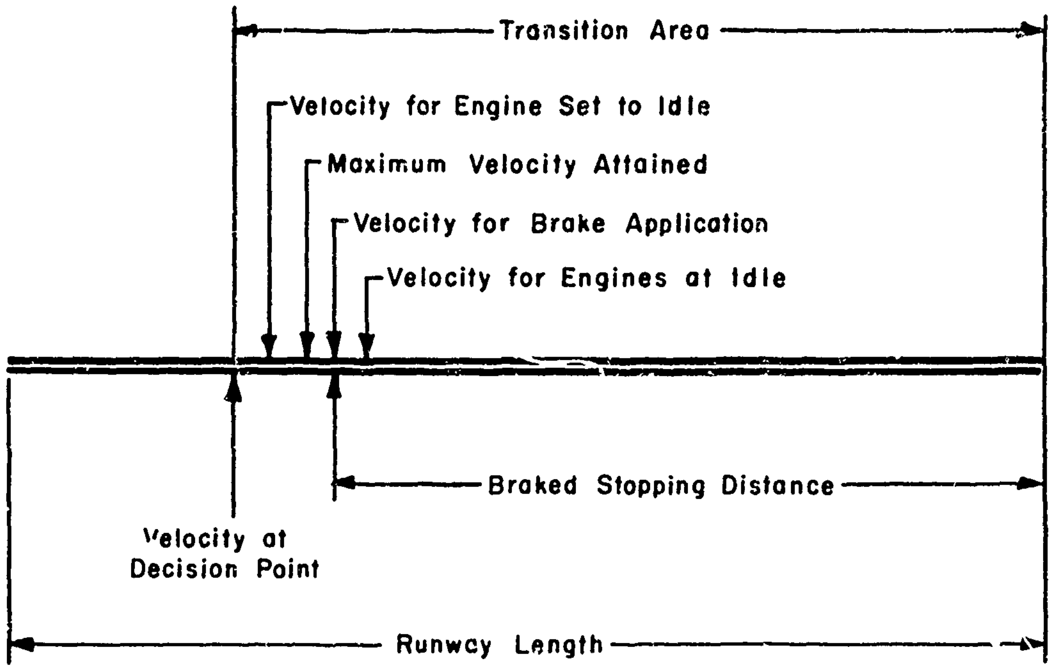
c. Rejected Takeoff

For the rejected takeoff, the starting time begins at the point of decision to abort or 1 second prior to brake application, whichever is earlier. The transition area includes all changes in configuration shown in Figure 6, plus any additional changes required for a specific aircraft.



NOTE: For maximum landing gross weight (5 stop) there is no allowance for reverse thrust; deceleration chute may be used if normally used for landing.

Figure 5. Parameters for Calculating Brake Energies for Landing and Stopping Distances



The runway length is such as to result in the greatest velocity possible such that engine failure permits acceleration to takeoff in the same distance that the aircraft may be decelerated to a complete stop @ 10 ft/sec² rate of deceleration by the brakes only.

Figure 6. Parameters for Reject Takeoff Type Stop

The rejected takeoff velocity is normally equal to 0.9 V_{spa}; however, the minimum abort velocity cannot be less than the maximum velocity resulting from critical engine failure (Reference 3). To determine the maximum abort velocity, V_m, we need values for the following factors:

a_n = acceleration with all engines for most adverse condition of temperature and altitude commensurate with aircraft operation

a_{n-1} = acceleration with all engines minus one for most adverse condition of temperature and altitude commensurate with aircraft operation

a_d = deceleration during braking (deceleration rate for brakes only is 10 ft/sec/sec, per Figure 6)

V_{to} = takeoff velocity

For this computation, the time, t, from deciding to abort until the brakes are applied will be considered to be 3 seconds; during this time period, the average velocity has increased to 1.05 V_m. The abort distance, S_A, then will be

$$S_A = \frac{(a_n + a_d) V_m^2 + 2 a_n a_d t 1.05 V_m}{2 a_n a_d}$$

and the takeoff distance after engine failure, S_{n-1}, will be

$$S_{n-1} = \frac{(a_n - 1 V_m^2 + a_n (V_{to}^2 - V_m^2}{a_{n-1}}$$

For maximum abort velocity, the distance to abort ideally should equal the distance to takeoff after loss of one engine; thus,

$$S_{n-1} = S_A$$

or

$$\frac{a_{n-1} V_m^2 + a_n (V_{to}^2 - V_m^2)}{a_{n-1}} = \frac{(a_n + a_d) V_m^2 + 2 a_n a_d t 1.05 V_m}{2 a_n a_d}$$

Therefore, the maximum abort velocity will be

$$2 a_n a_d \left[a_{n-1} V_m^2 + a_n (V_{to}^2 - V_m^2) \right] = a_{n-1} \left[(a_n + a_d) V_m^2 + 2.1 a_n a_d t V_m \right]$$

SECTION III

DETERMINING BRAKING ENERGIES

The following procedures are used for determining braking energies. The equations used in solving the forces, distances, and energies are given, as well as the inputs needed for use in these equations. A sample calculation is also given using each equation. The results of these sample calculations for forces and distances are presented in Table I. The results of the calculations for energies involved are presented in Table II.

1. FORCE AND DISTANCE COMPUTATIONS

The equation to use in computing each factor is given, followed by a sample computation. For these computations, the time starts at -1.00 second, and the initial velocity is assumed to be 230 ft/sec. The thrust includes that provided by all engines corrected for horizontal alignment with the ground, as given in Figure 1.

a. Aircraft Drag (D_A)

$$D_A = C_D \, q \, S_w$$

where

C_D = appropriate value determined from Figure 2

q = $1/2 \rho V^2$, and ρ = 0.00238 at sea level

S_w = 4000 ft^2 (for this example)

Therefore,

D_A = $0.12 \times 1/2 \times 0.00238 \times 230^2 \times 4000$

= 30,216 lbs

b. Brake Drag, B_D*

$$B_D = \mu\left[(P_M)(G.W. - C_L\ q\ S_W) + \left(\frac{(A_d)\,(C.G.\ Height)(G.W.)}{Nose\ to\ Main\ Dist(32.2)}\right) + \left(\frac{(\pm Thrust)(Height\ of\ Thrust\ Line)}{Nose\ to\ Main\ Wheel\ Dist}\right)\right]$$

where

μ = 0.41 for this example

P_M = appropriate value determined from Figure 4

G. W. = 240,000 lbs (for this example)

C_L = appripriate value determined from Figure 3

ρ = 0.00238

C.G. Height = 150 inches

Nose to Main Gear = 700 inches

Height of Thrust Line = 140 inches

thrust = appropriate value from Figure 1

A_d and reverse thrust are accompanied by negative signs.

Therefore,

$$B_D = .41\left[(0.85)\,(240{,}000 - (0.20)\,(0.00238)\,(204.9)^2(4000) + \frac{(-1.33)\,(150)\,(240{,}000)}{(700)\,(32.2)} + \frac{(+160)\,(140)}{(700)}\right] = 68{,}855 \text{ lbs.}$$

Considering the initial velocity to be 230 ft/sec at time -1.0 sec. resulted in a touchdown velocity of approximately 226 ft/sec at t = 0.0. Figure 5 indicates braking application would start at a velocity of 204.9 ft/sec at t = 14.50 seconds.

c. Deceleration Chute Drag, D_C (if applicable)

$$D_C = C_{DC}\ q\ S_c\ N\ (x)$$

where

C_{DC} and S_c are inputs provided by contractor

N = number of deceleration chutes

X = opening shock effect

---

*Prior to brake application, this value can be based on main gear rolling resistance calculated by $M_D = P_M\ (G.W. - C_L\ q\ S_W)\ 0.020$ = 441.31 lbs for this example. After brake application, this drag is no longer appropriate.

d. Nose Gear Drag, N_D

$$N_D = R_\mu \left[(P_N)(G.W. - C_L \; q \; S_w) - \left(\frac{(\pm A_d)\ (C.G.\ Height)\ (G.\ W.)}{(Nose\ to\ Main\ Dist)\ (32.2)} \right) - \left(\frac{(\pm\ Thrust)\ (Height\ of\ Thrust)}{(Nose\ to\ Main\ Wheel\ Dist)} \right) \right]$$

where

P_n = appropriate value from Figure 4

R_μ = 0.20 for this example

F = 2800 - 30216 = -27416 lbs.

$$A_d = \frac{(-27416)\ (32.2)}{(240,000)} = -3.68 \text{ ft/sec}^2$$

ΔV = -3.68 (0.25) = 0.9196 ft/sec

$$= (230 + \frac{(-0.9196)}{2}\ (0.25) = 57.39$$

e. Algebraic Summation of Forces, $\sum F$

$$\sum F = T + D_A + B_D + D_C + N_D$$

Example: At t = 1.0 sec

$\sum F$ = 2800 - 30,216 lbs = -27,416

f. Deceleration, A_d

$$A_d = \frac{\sum Fg}{G.W.}$$

Therefore

$$A_d = \frac{(-27,416)\ (32.2)}{(240,000)} = -3.68 \text{ ft/sec}^2$$

g. Incremental Change in Velocity, ΔV

$$\Delta V = a\, \Delta t$$

Therefore

ΔV = -3.68 (0.25) = 0.9196 ft/sec

h. Incremental Distance, Δd

$$\Delta d = (V + \frac{\Delta V}{2})\, \Delta t$$

Therefore

$$\Delta d = (230 + \frac{-0.9196}{2})\ (0.25) = 57.39 \text{ ft}$$

i. Total Distance Traveled ($\sum d$)

TABLE I

SUMMATION OF AIRCRAFT FORCES AND DISTANCES FOR SAMPLE CALCULATIONS

t (sec)	VEL (ft/sec)	(T) (lbs)	D_A * (lbs)	B_D * (lbs)	D_C (lbs)	N_D * (lbs)	$\sum F$ * (lbs)	A_d (ft/sec^2)	Δ VEL (ft/sec)	Δ d (ft)	$\sum$ d (ft)
-1.00	230.0000	2800.00	-30216.48	-0.	N/A	0.	-27416.48	-3.68	-0.9196	57.39	57.39
-0.75	229.0804	2800.00	-29975.34	-0.	N/A	0.	-27175.34	-3.65	-0.9115	57.16	114.54
-0.50	228.1689	2800.00	-29489.46	-0.	N/A	0.	-26689.46	-3.58	-0.8952	56.93	171.47
-0.25	227.2737	2800.00	-29012.64	-0.	N/A	0.	-26212.64	-3.52	-0.8792	56.71	228.18
0.00	226.3945	2810.00	-28056.69	-0.	N/A	0.	-25246.69	-3.39	-0.8468	56.49	284.67
0.25	225.5477	2820.00	-26636.44	-441.31	N/A	0.	-24257.75	-3.25	-0.8136	56.29	340.96
0.50	224.7340	2830.00	-24521.37	-953.51	N/A	0.	-22644.88	-3.04	-0.7595	56.09	397.05
3.25	220.1146	2450.00	-6918.72	-3645.65	N/A	-118.46	-8232.53	-1.10	-0.2761	54.99	1006.35
14.50	204.8990	160.00	-5995.26	-68854.83	N/A	-641.86	-75331.94	-10.11	-2.5268	50.91	3393.27

*All minus signs indicate forces in a direction opposite to that of aircraft travel.

2. ENERGY COMPUTATIONS

The energy to be dissipated in the braking process can be determined by multiplying the incremental forces (T, D_A, B_D, D_C, and N_D) by the incremental distances (Δ d) and summing for the total. Values for the example (aircraft with a G. W. of 240, 000 lbs and an initial velocity of 230 fps) have been computed and are presented in Table II. Inputs for the various columns are as follows:

a. Time (t) - in increments of 0. 25 sec, as in Table I.

b. Kinetic Energy (K. E.) - value determined from the following equation:

$$K.E. = 1/2 \frac{G.W.}{g}$$

c. Total Engine Energy - to include the total amount of thrust for the given time period.

d. Total Aircraft Drag Energy

e. Increment of Brake Energy

f. Total Brake Energy

g. Total Deceleration Chute Energy

h. Total Nose Gear Drag Energy

i. Summation of Energies - to include the algebraic sum of columns c, d, f, g, and h.

TABLE II

SUMMATION OF ENERGIES FOR SAMPLE CALCULATIONS

a	b	c	d	e	f	g	h	i
t (sec)	K. E. (ft/lbs)	E. E. (total)	D_AE (total)	B. E. (inc)	B. E. (total)	D_CE (total)	N_DE (total)	Sum of Energies
-1.00	197,142,855	160,678	-1733,974	0.	0.	N/A	0.	-1573,296
0.00	191,010,395	797,649	-8356,358	-0.	0.	N/A	0.	-7558,709
0.25	189,584,137	956,373	-9855,595	-24,839	-24,839	N/A	0.	-8924,061
0.50	186,218,781	1115,104	-11230,964	-53,481	-78,320	N/A	0.	-10194,180
3.25	180,560,598	2805,905	-18064,806	-200,489	-1769,567	N/A	-6,514	-17034,983
14.50	156,460,602	3545,777	-33457,217	-3505,324	-13142,046	N/A	-1463,728	-44517,214

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

The procedures described in this report permit an accurate determination of the braking forces and distances required for stopping an aircraft. These procedures require input data different from that required by MIL-W-5013. It is recommended that input data as specified herein be required of all Air Force aircraft manufacturers and that this data be used as described herein to evaluate aircraft designs.

REFERENCES

1. Military Specification, MIL-W-5013, "Wheel and Brake Assemblies; Aircraft."

2. Military Specification, MIL-A-8862, "Airplane Strength and Rigidity Land Plane Landing and Ground Handling Loads."

3. Military Specification MIL-M-7700, "Manuals, Flight."

UNCLASSIFIED
Security Classification

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) Deputy for Engineering, Aeronautical Systems Division Wright-Patterson Air Force Base, Ohio	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

AIRCRAFT BRAKE ENERGY ANALYSIS PROCEDURES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Dale E. Creech

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1968	26	3

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	ASD-TR-68-56
c. System 139A	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Deputy for Engineering Aeronautical Systems Division Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

This report describes a standardized method for analyzing and calculating aircraft brake energy requirements. The method is an adaptation of method II of MIL-W-5013 and requires exact inputs readily adapted to computer use. These methods have been used in an analysis of the C-5A, F-111, and AMSA aircraft brake energy requirements. Programming the equations into a computer gave very satisfactory results. The methods can be used manually or by a computer to determine the braking energy requirements of any aircraft.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft Landing Systems						
Aircraft Braking Analysis						

UNCLASSIFIED
Security Classification

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: ASNFL (Mr Creech)

29 APR 1969

SUBJECT: ASD TR-68-56, Aircraft Brake Energy Analysis Procedures

TO: Clearinghouse for Federal Scientific & Tech Info
Sills Building
5285 Port Royal Rd
Springfield, Va 22151

AD 685775

Attached hereto is the errata sheet for pages 12, 14 and 15 of the subject technical report.

H R CHANDLER
Acting Chief, Landing Gear and
Mechanical Equipment Division
Directorate of Airframe Subsys Engr

1 Atch
Errata Sheet

ERRATA SHEET FOR ASD TR-68-56

1. On page 12:

   a. The equations for S_A and S_{n-1} equal the total field distance.

   b. For the equation S_{n-1} the denominator should be "$2a_n a_{n-1}$." Therefore, the final equation should read as follows:

$$2a_n a_d \left[a_{n-1} V_m^2 + a_n \left(V_{to}^2 - V_m^2\right)\right] = 2a_n a_{n-1} \left[(a_n + a_d) V_m^2 + 2.1 a_n a_d t V_m\right]$$

2. On page 14:

   a. Change the "+" sign to a "-" sign as follows:

$$- \left(\frac{(\pm \text{Thrust})(\text{Height of Thrust Line})}{\text{Nose to Main Wheel Distance}} \right)$$

   b. The B_D sample calculation has the proper answer but should read as follows:

$$B_D = .41 \left[(.85) \left((240{,}000) - \frac{(\text{[redacted]})(0.00238)(204.9)^2(4000)}{2} \right) + \left(\frac{(-1.33)(150)(240{,}000)}{(700)(32.2)} \right) - \left(\frac{(+160)(140)}{(700)} \right) \right] = 68{,}855$$

3. Page 15, change the "-" sign to a "+" sign as follows:

$$+ \left(\frac{(\pm \text{Thrust})(\text{Height of Thrust})}{\text{Nose to Main Wheel Distance}} \right)$$