# 16

# FAR REQUIRED TAKEOFF FIELD LENGTH

## FAR 25 GENERAL REQUIREMENTS

The takeoff field length required by the FAR 25.113 for jet transport operation with a specified TOGW, from an airport at a specific pressure altitude and ambient temperature is the greater of

1. The all engine takeoff distance x 1.15
2. The takeoff distance with an engine failure at the "most critical point" in the takeoff.

For the takeoff with an engine failure, there are 3 situations:

1. Engine failure at a point ($V_{EF}$) sooner than most critical point—stop on runway.
2. Engine failure at a point ($V_{EF}$) later than most critical point—continue takeoff with 1 engine failed.
3. Engine failure at the "most critical point" where the distance to stop on runway equals the distance to continue takeoff with 1 engine failed to a height of 35 ft. This is called the balanced field length concept.

These conditions are illustrated in Fig. 16-1.

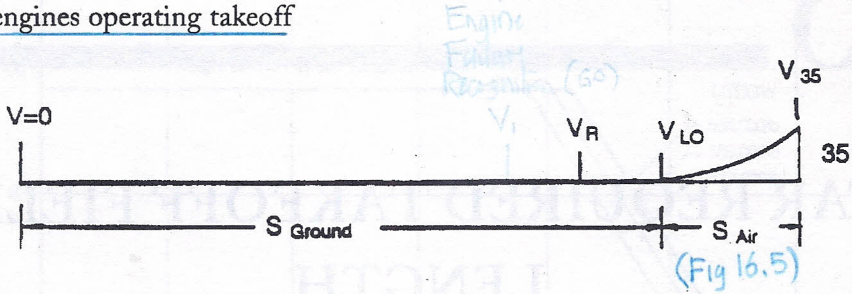
"Most critical point" in a given takeoff where the "accelerated-stop" distance is equal to the "accelerated-continue-distance" is found by plotting "accelerate-stop" distance and "accelerate-continue" with 1 engine failed versus not $V_{EF}$, but the engine failure recognition speed, called $V_1$ as shown in Fig. 16-2.

For propeller driven transports the FAR balanced field length concept is the same, but

## FAA REQUIRED TAKEOFF FIELD LENGTH

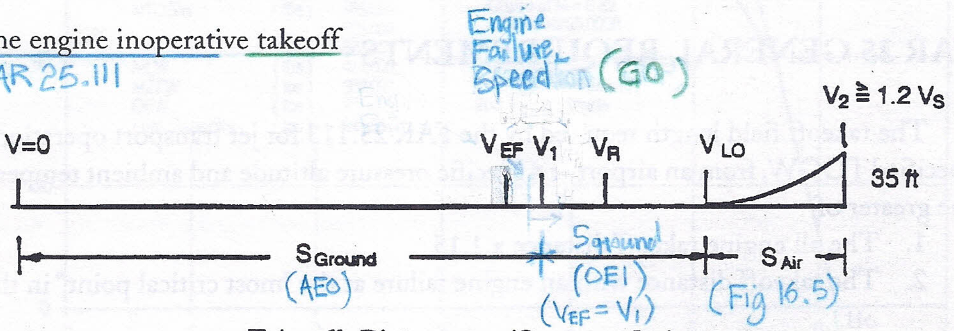
### For a specific gross weight, altitude, and temperature

1. All engines operating takeoff



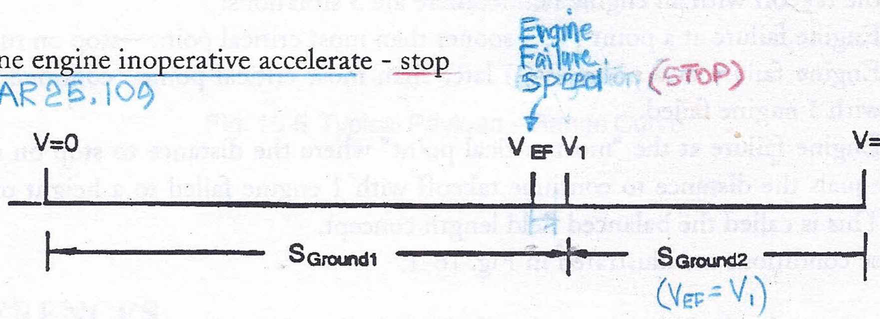

Takeoff Distance = $(S_{Ground} + S_{Air}) \times 1.15$ ← NB

2. One engine inoperative takeoff
FAR 25.111




Takeoff Distance = $(S_{Ground} + S_{Air})$

3. One engine inoperative accelerate - stop
FAR 25.109




Accelerate - Stop Distance = $(S_{Ground1} + S_{Ground2})$

- Balanced field length requires that 2 and 3 be equal
- FAA required field length is the greater of 1 or 2

Fig. 16-1 FAA Required Takeoff Field Length

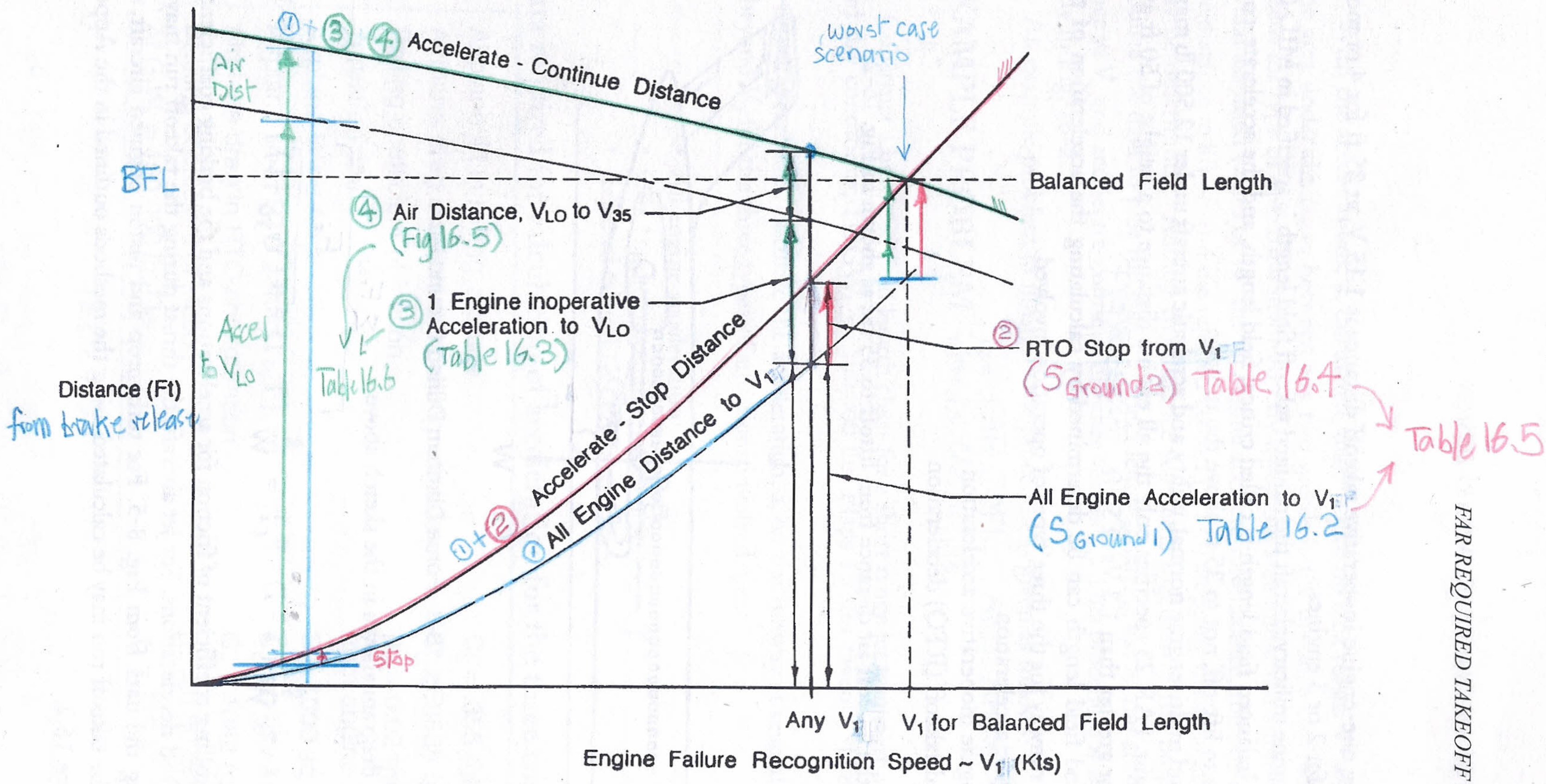



Fig. 16-2 Balanced Field Length Concept

the speed for the one-engine inoperative takeoff distance is 1.15 $V_s$ at 35 ft for 4 or more engines, 1.2 $V_S$ for 2 or 3 engines.

For multi-engine military aircraft the required takeoff field length is specified in MIL-C-5011B, and the balanced field length is called critical field length, and the accelerate-continue distance is to lift-off, not to 35 ft above the runway.

For single and multi-engine normal, utility, and acrobatic aircraft under 12,500 lb maximum gross weight, FAR 23 specifies only the all engine distance to a height of 50 ft at a speed equal to or greater than 1.3 Vs at 50 ft. FAR 23.51(c)(4)

The balanced field length can be determined by calculating the acceleration of the airplane on the runway for the three types of operation involved.

- All engine acceleration
- One engine inoperative acceleration
- Rejected takeoff (RTO) deceleration

and adding on the takeoff air distance from liftoff to 35 ft., as shown in Fig. 16-2.

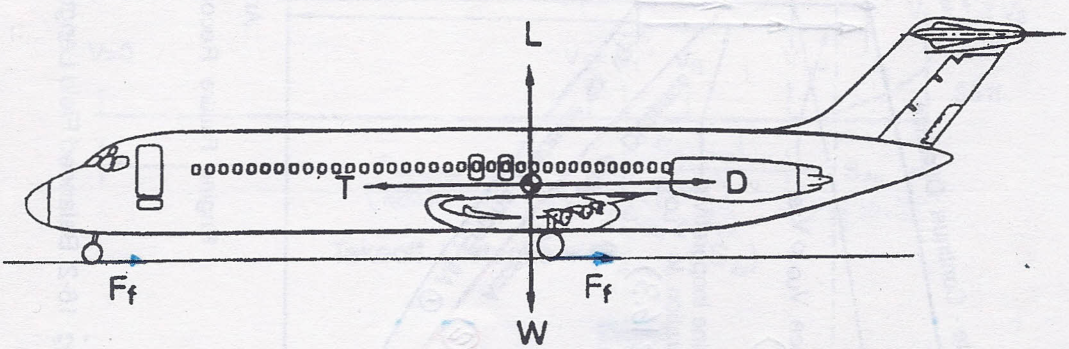



Fig. 16-3 Force Diagram During Ground Run

From the force diagram shown in the sketch above

$$a = \frac{g}{W}[T - D - F_f] = \frac{g}{W}[\overbrace{T - D - \overbrace{\mu(W_{TO} - L)}^{F_f}}^{\Sigma F_{rw}}] \qquad (16\text{-}1)$$

where $\mu$ is the rolling coefficient of friction for accelerations and the braking coefficient of friction for braked decelerations. For jet aircraft, the thrust during the takeoff run may be calculated using the data from Fig. 8-5. For turboprop and piston engined aircraft, the thrust during the takeoff run may be calculated using the methods outlined in the Appendix to Reference 16.2.

With the accelerations, a, calculated, make a plot of 1/2a versus $V^2$ where V is in fps. The area under the curve between any two speeds is the distance covered between those speeds for type of operation involved. By using the area under the appropriate curves for several assumed values of $V_1$ the all engine acceleration distance, the one engine inoperative distance to lift off and the rejected takeoff (RTO) stopping distance at the assumed $V_1$ may be determined. Adding the distance segments together in the proper manner will produce the data to plot the balanced field length chart. That is, the accelerate-stop distance vs $V_1$ and accelerate-continue distance versus $V_1$. This procedure is shown schematically in Fig. 16-2.

An example problem to illustrate the procedure is given as follows:

## EXAMPLE PROBLEM

For FAR TOFL, AEO takeoff distance must also be calculated

Construct a balanced field length chart for a short range jet transport at sea level standard day conditions, TOGW = 100,000 lbs, Flaps 15° for takeoff, JT8D-7 engines.

From given data, calculate the acceleration, a, on the runway at several speeds, from 0 to beyond $V_2$ for the three types of situations involved, i.e.,

- All engine acceleration
- One engine inoperative acceleration
- Rejected takeoff (RTO) deceleration

### Data required for calculation of acceleration for the three conditions:

| | |
|---|---|
| Airplane lift in rolling attitude | $C_L$ = .355 (given) |
| Airplane drag coefficient in rolling attitude | $C_D$ = .0585 (given) |
| Rolling coefficient of friction | $\mu_R$ = 0.02 (given) |
| Thrust/engine | from engine data |
| Airplane Wing Area | S = 1000 sq ft (given) |
| Airplane lift in RTO configuration | $C_L$ = 0 (given) |
| Airplane drag in RTO configuration | $C_D$ = .1082 (given) |
| Braking coefficient of friction | $\mu_B$ = 0.30 (given)* |
| At G.W. = 100,000 lb, Flaps 15° | $V_s$ = 110 KTS EAS |

Table 16.1

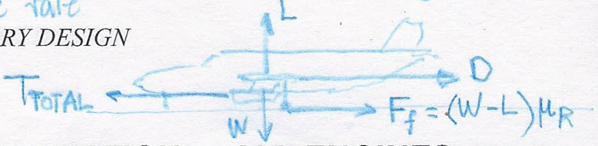
*
Jenkinson 0.3
Kundu 0.3
Raymer 0.5
Nicolai 0.32

For DC-9 typical buildup is
Flaps 15°
Spoilers 40°

$C_{D_{clean}}$ = 0.0200 p232
$C_{D_{flaps}}$ = 0.0070 f. 12-15
$C_{D_{spoilers}}$ = 0.0500 f. 12-15
$C_{D_{gear}}$ = 0.0250 f. 12-17
$C_{D_{slats}}$ = 0.0060 f 12-15

* According to Fig 8-5, this corresponds to a very LBPR jet engine (not a JT8D-7)
Use Fig 8-5 for more typical lapse rate






## Table 16.2 CALCULATION OF ACCELERATION — ALL ENGINES

AEO
$V_{LO}$ = 129 KEAS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $V_{KTS}$ | 0 | 40 | 80 | 120 | 140 | |
| | Mach | 0 | .060 | .120 | .181 | .211 | |
| (updated) Fig 8-5 | T/Eng(lbs) | 13,500 | 13,200 | 12,700 | 12,300 | 12,100 | (90%) |
| 2× T/eng = | $T_{TOTAL}$ (lbs) | 27,000 | 26,400 | 25,400 | 24,600 | 24,100 | |
| | $C_D$ (p.289) | .0585 | .0585 | .0585 | .0585 | .0585 | |
| | q (psf) | 0 | 5.3 | 21.3 | 48.5 | 65.9 | |
| $C_D q S$ = | D (lbs) | 0 | 310 | 1250 | 2840 3452 | 3860 | |
| | $C_L$ (p 289) | .355 | .355 | .355 | .355 | .355 | |
| $C_L q S$ = | L (lbs) | 0 | 1892 | 7561 | 17,220 | 23,400 | |
| | W (lbs) | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | |
| | W-L (lbs) | 100,000 | 98,110 | 92,440 | 82,800 | 76,600 | |
| $=(W-L)\mu_r$ = | $F_f$ (lbs) | 2,000 | 1,960 | 1,850 | 1,860 | 1,520 | |
| $(T_{Total} - F_f)$ = | Σ Frw (lbs) | 25,000 | 24,130 | 22,300 | 20,100 | 18,720 | |
| =n 16.1 → | a (ft/sec²) | 8.04 | 7.79 | 7.20 | 6.49 | 6.05 | |
| | 1/2a (ft/sec²) | .0622 | .0643 | .0695 | .0771 | .0826 | Plot on Fig 16-4 |
| | $V^2$ (fps)² | 0 | 4,480 | 17,960 | 40,800 | 55,450 | |
| | | (a) | (b) | (c) | (d) | (e) | or use Excel |

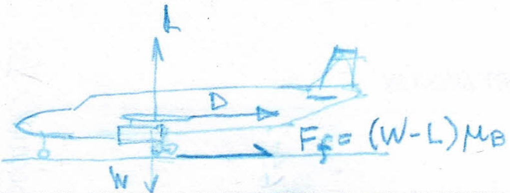
## Table 16.3 CALCULATION OF ACCELERATION - ONE ENGINE INOPERATIVE

Since all parameters for this situation are the same as for the all engine acceleration, except for the engine thrust,* the sum of the forces along the runway are reduced by the thrust of one engine.

$V_{ss}$ = 132 KEAS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $V_{KTS}$ | 0 | 40 | 80 | 120 | 140 | |
| | Σ $F_{RW}$ (lbs) | 25,000 | 24,130 | 22,300 | 20,000 | 18,720 | |
| | T/Eng (lbs)* | 13,500 | 13,200 | 12,700 | 12,300 | 12,100 12180 | |
| | Σ Frw (lbs) (eng. inop.)(lbs) | 11,500 | 10,930 | 9,600 | 7,800 | 6,620 | |
| =n16.1 → | a (ft/sec)² | 3.70 | 3.52 | 3.06 | 2.51 | 2.13 | |
| | 1/2a (sec²/ft) | .135 | .142 | .163 | .199 | .235 | Plot on Fig 16-4 |
| | $V_2$ (ft/sec)² | 0 | 4480 | 17,450 | 40,800 | 55,450 | |
| | | (f) | 4558 (g) | 18,225 (h) | 41,006 (i) | 55,838 (j) | or use Excel |

* Neglect drag of windmilling engine + Trim




## CALCULATION OF ACCELERATION — REJECTED TAKEOFF (RTO)

Table 16.4 DE

Thrust/Engine = 0 (one engine failed, one shut down)

| | | | | | |
|---|---|---|---|---|---|
| $V_{KTS}$ | 0 | 40 | 80 | 120 | 140 |
| q (psf) | 0 | 5.3 | 21.3 | 48.5 | 65.9 |
| $C_D$ | .1082 | .1082 | .1082 | .1082 | .1082 |
| D (lbs) | 0 | 580 | 2305 | 5250 | 7130 |
| W - L (lbs) * | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 |
| $F_f$ (lbs) | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 |
| $F_{RW}$ (lbs) | 30,000 | 30,580 | 32,300 | 35,250 | 37,130 |
| =n16.1 a (ft/sec²) | -9.65 | Ave -9.89 | -10.40 | -11.35 | -11.95 |
| 1/2a (sec²/ft) | -.0518 | -.0514 -.0510 | -.0431 | -.0440 | -.0418 |
| V² (ft/sec²) | 0 | 4,480 | 17,950 | 40,800 | 55,450 |
| | (k) | (l) | (m) | (n) | (o) |

Plot on Fig 16-4 or use Excel

Plot 1/2a versus V² for the three conditions, Fig. 16-4, and obtain appropriate distances before and after assumed $V_1$ by integrating the area between corresponding values of $V_1$. This procedure yields the results shown below.

## DETERMINATION OF ACCELERATE-STOP DISTANCES

Table 16.5

(using the 1/2a curves of Fig. 16-4)

| $V_1$ (kts) KTAS | 0 | 40 | 80 | 120 | 140 |
|---|---|---|---|---|---|
| Table 16.2 Accelerate to $V_1$ (ft) | 0 | 290 (B) | 1150 | 2860 | 4040 |
| Table 16.4 Stop from $V_1$ (ft) | 0 | $\boxed{230}$ (A) | 870 | 1950 | 2580 |
| Accelerate-Stop (ft) | 0 | 520 | 2020 | 4310 | 6620 |

Plot on Fig 16-6

see example on p 292

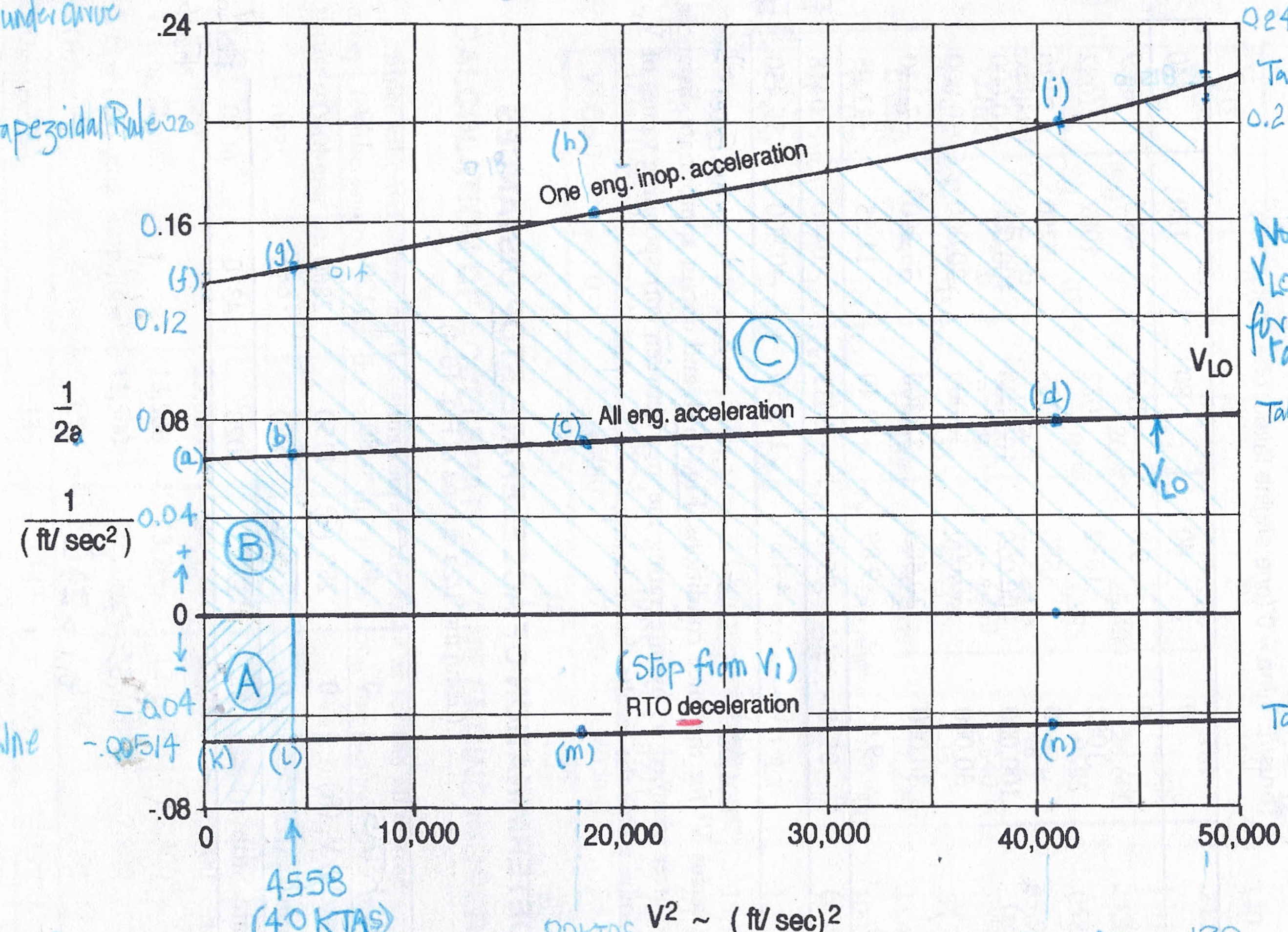
* Spoilers may be used on RTO. Lift may be -ve. Here L = 0

$V^2 = u^2 + 2as$

$u = 0 \quad S = \frac{V^2}{2a}$ = area under curve

But easier to use Trapezoidal Rule

MUCH EASIER TO USE A SPREADSHEET




Av value -.0514

Note that $V_{LO}$ is reduced for AEO takeoff because $V_{35}$ has increased $V_{LO}$ (Fig 16.5 lower)

Fig. 16-4 Takeoff Acceleration ~ Deceleration Chart

(A) Area under curve $= -0.0514 \frac{\text{sec}^2}{\text{ft}} \times 4480 \frac{\text{ft}^2}{\text{sec}} = 230$ ft (see Table 16.5)

## Determination of accelerate-continue distances to $V_2$

**(using the 1/2a curves + the takeoff air distance curves)**

The accelerate-continue distance to $V_{LO}$ on the runway is found from the 1/2a curves. The air distance part of the accelerate - continue distance is found from empirical correlations based on flight test data involving the time required to go from liftoff to 35 ft, and the speed increase from liftoff to 35 ft. These parameters are shown in Fig. 16-5 as $S_a/V_{LO}$ and $V_{35}/V_{LO}$, as a function of free air climb gradient in the takeoff configuration.

As we shall see in Chapter 17, the minimum free air climb gradient for a twin-engine transport is .024, a reasonable choice for determining the air distance in our example.

The $V_{35}/V_{LO}$ curve is used to determining $V_{LO}$ using the fact that $V_{35} = 1.2V_{Stall}$ for one-engine inoperative takeoff. For our sample calculations

FAR hence find $V_{LO}$

110 KEAS (Fig 16.1) or Ch 11

$V_{35}$ = 1.2 $V_S$ = 132 Kts

use in → upper

$\gamma$ = (T - D)/W = .024 $\quad$ $S_a/V_{LO}$ = 6.2 sec (Fig 16.5) $\quad$ $V_{35}/V_{LO}$ = 1.012 (Fig 16-5) (lower)

$V_{LO}$ = 130 Kts $\quad$ $S_a$ = 130 (1.69)(6.2) = 1360 ft

Table 16.6

| $V_1$ (Kts) | 0 | 40 | 80 | 120 |
|---|---|---|---|---|
| Accelerate to $V_1$ (ft) (Table 16.2) | 0 | 290 B | 1150 | 2860 |
| Continue to $V_{LO}$ (ft) (Table 16.3) | 8190 | 7580 C | 5700 | 1370 |
| Air Distance (ft) (Fig 16.5) | 1360 | 1360 | 1360 | 1360 |
| Accelerate Continue (ft) | 10550 | 9230 | 8210 | 5590 |

Plot on Fig 16.6

Determination of accel-continue distances

The accelerate-stop and accelerate-continue curves are plotted versus assumed $V_1$ on Fig. 16-5. The final values from Fig. 16-5 are:

- Critical engine failure recognition speed, $V_1$ = 123 Kts
- Balanced field length = 5200 ft

## FAR 23 REQUIREMENTS

For aircraft certified under FAR 23, the takeoff field length must be determined by flight test and included in the FAA flight manual. For FAR 23 commuter category aircraft, the balanced field length concept is applied and the criteria for the takeoff are basically the same as for FAR 25, except that the takeoff distance is defined to a 50 ft height instead of 35 ft, and the $V_2$ speed must be at least 1.3 $V_S$. For other FAR 23 category aircraft, the balanced field length concept is not generally applicable to single engine aircraft, and so only the takeoff field length with all engines operating must be determined and included in

under 6,000 lb
See FAR 23.53 (c)

See FAR 23.3 (a) Normal
(b) Utility
(c) Acrobatic
(d) Commuter

the aircraft flight manual.

The FAR 23 takeoff field length for preliminary design purposes may be determined with sufficient accuracy for personal/utility aircraft from the trend data of Fig. 8-2. As noted, this chart is based on a correlation of actual takeoff field length data for a number of aircraft with the generalized takeoff parameter.

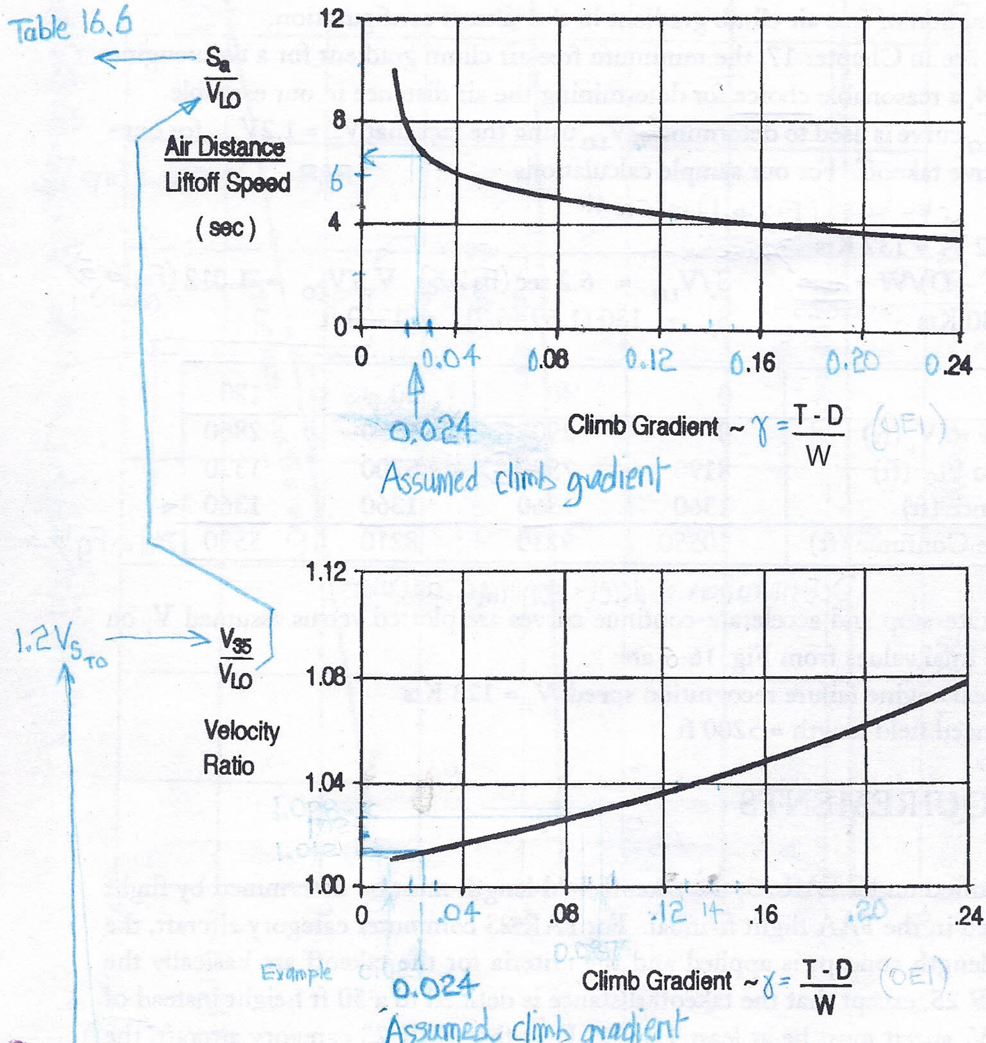



Fig. 16-5 FAR 25 Air Distance Parameters

$$V_{S_{TO}} = \sqrt{\frac{2W}{\rho C_{L_{TO}} S}}$$

START HERE → Fig 11.3

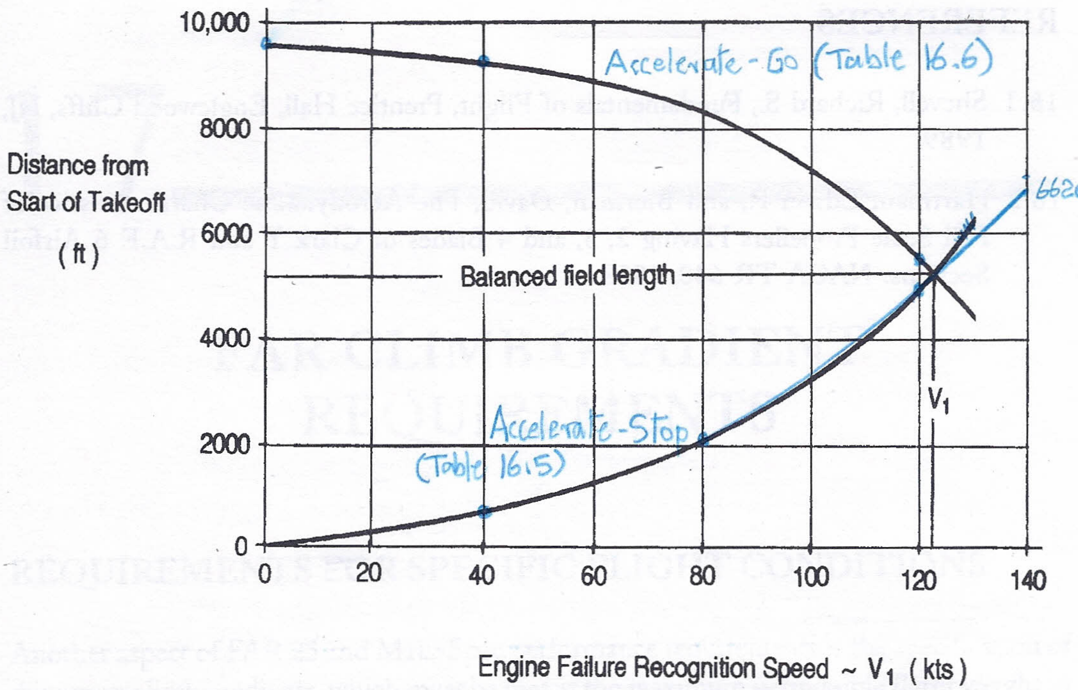



Fig. 16-6 Takeoff Acceleration-Deceleration Chart

## DESIGN EXERCISE

Determine the required FAR 23, FAR 25, or MIL-C-5011B takeoff field length for your design at MTOGW, using the procedures of Part 16. Compare your result with the data on the appropriate generalized takeoff chart of Figs. 8-2 through 8-4 by plotting your calculated point on the generalized chart. Then put a faired curve similar to the generalized curve through your calculated point, and use this curve to construct a chart of takeoff distance vs takeoff weight for sea level and 2000 ft altitude standard day conditions. Also calculate the ground minimum control speed, $V_{mcg}$, using the method illustrated in Fig. 6-14, for sea level standard day conditions. (and described in Annotation for Ch 6)

To calculate AEO takeoff to 35'

1. Assume $V_{LO}$ as for OEI
2. Calc T + D + hence $\gamma = \frac{T-D}{W}$
3. Use Fig 16-5 to calc new $V_{LO}$ + new $S_A$
3. Use spreadsheet to calc $S_G$ to new $V_{LO}$
4. $TOD_{AEO} = (S_G + S_A) \times 1.15$
5. FAR TOFL = Greater of $(BFL, TOD_{AEO})$