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Possible "Impossible" Turn

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Turning back after engine failure during the takeoff phase of flight in a single engine aircraft is examined using a simplified analytical model. The important parameters are identified. The analysis shows that the optimum flight path is teardrop-shaped with a 45-deg bank angle at stall velocity during the turn. The effects of engine failure altitude, wind direction and velocity, climbout velocity, bank angle, and velocity in the turn on the required runway length are examined. The results show that the typical recommendations for general aviation single engine aircraft are not optimum.

Nomenclature

C_D = drag coefficient
C_{D_0} = zero lift drag coefficient
C_L = lift coefficient
$C_{L_{max}}$ = maximum lift coefficient
D = drag
d = propeller diameter
g = acceleration of gravity
h = altitude
J = advance ratio
L = lift
L/D = lift-to-drag ratio
n = propeller rpm
R = turn radius
R/C = rate of climb
S = wing area
t = time
V = velocity
V_{cruise} = cruise velocity
$V_{L/D_{max}}$ = velocity for maximum L/D
$V_{R/C_{max}}$ = velocity for maximum rate of climb
$V_{stall(clean)}$ = stall velocity gear and flaps up
$V_{stall(dirty)}$ = stall velocity gear and flaps down
$V_{turning}$ = velocity in a coordinated turn
$V_{\gamma_{max}}$ = velocity for maximum climb angle
W = weight
η = propeller efficiency
ϕ = bank angle
ρ = density
Ψ = turn angle or heading
$\dot{\Psi}$ = turn rate

Introduction

IF the engine of a single engine aircraft stops during the initial climb segment immediately after takeoff, conventional wisdom, and the Federal Aviation Administration (FAA) recommended procedure, is for the pilot to land straight ahead.[1,2] Furthermore, the FAA recommends that under no circumstance should the pilot attempt to turn back and land on the departure runway.[3] Specifically, Ref. 3 states: "Turning back is the worst possible action when the power plant fails during climbout in a single." Certainly this is true if the engine quits at 10, 50, 100, or 200 ft. But what if the failure altitude is 300–1000 ft? Can a turn back to the departure or an intersecting runway be successfully completed? What is the proper procedure for the gliding turn and subsequent power-off glide to a landing? What are the principal variables in the problem?

This problem is of particular interest to general aviation pilots of single engine aircraft. It is becoming of increasing interest to corporate and commercial operators, with the increase in the number of single engine high-performance turboprop aircraft available for these operations. Unfortunately, the literature that exists, generally in the "popular" aviation press, makes recommendations that are demonstrably incorrect. A notable exception is the discussion by Schiff.[4] Schiff experimentally correctly determined that the optimum bank angle in the turn is 45 deg, and the optimum flight path is teardrop-shaped. Unfortunately, Schiff's experiments used the velocity for maximum straight-ahead glide ratio $V_{L/D_{max}}$ in the turn, and the velocity for maximum rate of climb $V_{R/C_{max}}$ during climbout, both of which are nonoptimum.

A good example of an "analytical" article that makes demonstrably incorrect recommendations is that by Eckalbar.[5,6] Using a Beech A36 Bonanza as an example and assuming no wind, he recommends initially climbing at the velocity for maximum rate of climb to a minimum of 1000 ft above ground level (agl) along the runway centerline extended, where engine failure is assumed to occur. A 270-deg unpowered gliding turn, followed by an additional 90-deg unpowered gliding turn in the opposite direction to realign the aircraft with the runway, is then performed. A velocity of $1.3V_{stall(clean)}/\sqrt{\cos\phi}$ with a 35-deg bank angle is recommended for the turn. Upon completion of the turn the aircraft is accelerated to the velocity for L/D_{max} and continues to a landing. All transitions are assumed to occur instantaneously. Each of these recommendations, taken individually, is nonoptimum. Collectively they result in failure of the aircraft to successfully complete the maneuver whenever the departure runway is less than 6000+ ft long. Since most aircraft of this type operate out of airports with runways considerably less than 6000 ft in length (typically 3000 ft in length), an off-airport landing is likely. As the analysis below shows, the velocity for maximum climb angle is a better choice for the initial climb segment, and the minimum altitude above ground level is considerably less than 1000 ft agl. A teardrop flight path, as shown in Fig. 1, with a turn of approximately 210 deg performed at $1.05V_{stall(clean)}/\sqrt{\cos\phi}$ at a 45-deg bank angle results in a more nearly optimum and more likely to succeed maneuver. By using this procedure the required runway length is reduced by approximately a factor of 8.

Optimum Bank Angle and Velocity

Following the development in Ref. 7, we consider a simple energy analysis of the optimum conditions for a steady gliding

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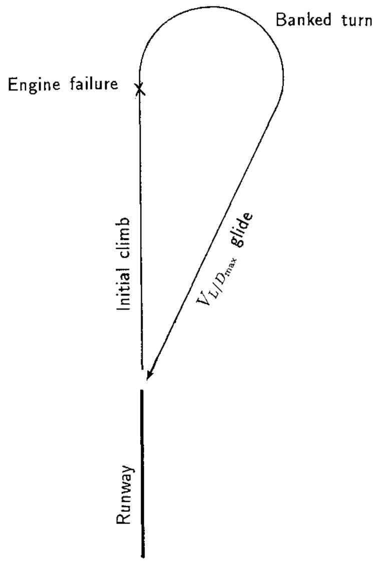

Fig. 1 Teardrop flight path.

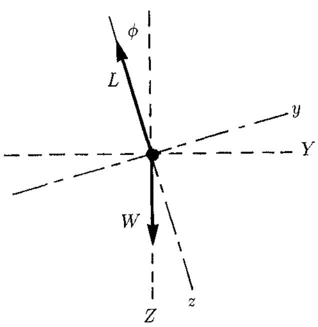

Fig. 2 Forces in the *yz* plane in a steady-state gliding turn.

turn to a new heading. In a gliding turn the aircraft trades the potential energy embodied in altitude to overcome drag and maintain velocity above the stall velocity of the aircraft. A larger bank angle in the gliding turn requires a higher rate of descent to maintain steady conditions, but results in a larger rate-of-change of heading. Consequently, maximizing the heading change with altitude loss in the gliding turn to a new heading yields the optimum turn conditions. From Fig. 2 we have

$$L \cos \phi = \tfrac{1}{2}\rho V^2 S C_L \cos \phi = W \tag{1}$$

$$L \sin \phi = (V^2/R)(W/g) \tag{2}$$

where V^2/R is the horizontal acceleration. Combining Eqs. (1) and (2) yields the radius of the turn, i.e.,

$$R = V^2/g \tan \phi \tag{3}$$

Minimizing the radius of the turn keeps the aircraft close to the end of the runway and results in a decreased glide distance after completion of the turn.

In a steady-state turn, the heading change Ψ per unit time is

$$\dot{\Psi} = \frac{d\Psi}{dt} = V/R = \Psi/t \tag{4}$$

The rate at which the aircraft expends the potential energy available from altitude must equal the energy required to overcome drag. Thus

$$W\frac{dh}{dt} = DV \tag{5}$$

Integrating for steady-state conditions yields

$$h = DVt/W \tag{6}$$

Introducing Eqs. (3) and (4) yields

$$h = (D/W)V^2(\Psi/g \tan \phi) \tag{7}$$

In a gliding turn with bank angle ϕ

$$D/W = C_D/C_L \cos \phi \tag{8}$$

and recalling that

$$V^2 = 2W/\rho S C_L \cos \phi \tag{9}$$

Eq. (7) is written as

$$h = \frac{C_D}{C_L^2}\frac{4W}{\rho S g}\frac{1}{\cos \phi \sin \phi}\Psi \tag{10}$$

The steady-state conditions for minimum loss of altitude in a gliding turn to a new heading are obtained by differentiating Eq. (10). The result is

$$\frac{dh}{d\Psi} = \frac{C_D}{C_L^2}\frac{8W}{\rho S g}\frac{1}{\sin 2\phi} \tag{11}$$

where we used $\sin 2\phi = 2 \sin \phi \cos \phi$.

Examining this result shows that for a parabolic drag polar, $C_D = C_{D_0} + kC_L^2$, the first term

$$C_D/C_L^2 = (C_{D_0}/C_L^2) + k \tag{12}$$

is a minimum at $C_{L_{max}}$. Thus, the optimum speed for minimum loss of altitude in a gliding turn to a new heading occurs for $C_{L_{max}}$, i.e., at the stall velocity. Neglecting the small density change with altitude, the second term, $8W/\rho Sg \sin 2\phi$, is a minimum for $\sin 2\phi = 1$ or $\phi = 45$ deg, i.e., the optimum bank angle during a gliding turn to a new heading is 45 deg.

Simplified Model

A complex numerical integration of the aircraft equations of motion starting from initial brake release could be used to address the problem. However, a simplified "analytical" model is adequate to illustrate the major aspects of the problem.

The simplified model uses data from the manufacturer's pilot's operating handbook (POH) for the subject aircraft to determine the initial takeoff ground roll, rotation and liftoff velocities, and the distance over a 50-ft obstacle. An instantaneous transition from the velocity at 50 ft to the specified climbout velocity is assumed. A steady climb at constant velocity from 50 ft to the failure altitude while maintaining runway heading is assumed. At engine failure an instantaneous transition to a coordinated banked descending gliding turn at the assumed bank angle and the assumed velocity is used. Upon completion of the turn, an instantaneous transition to the velocity for L/D_{max} is assumed. A glide at $V_{L/D_{max}}$ until touchdown is assumed. No allowance for the effects of landing gear retraction/extension are made.

Aircraft

The example aircraft chosen for study is a Model 33A 285 bhp single engine retractable Beech Bonanza. A three-view drawing is shown in Fig. 3. The aircraft characteristics are given in Table 1.

The drag polar for the aircraft is assumed parabolic, i.e.,

$$C_D = C_{D_0} + kC_L^2 \tag{13}$$

Table 1 Beech Bonanza Model 33A characteristics

Gross weight	3300 lb
Wing area	181 ft^2
L/D_{max}	10.56
Power	285 bhp
Propeller	Constant speed 3-blade
V_{cruise} at 65%	190 mph
$V_{stall(clean)}$ power off	72 mph
$V_{stall(dirty)}$ power off	61 mph
$V_{L/D_{max}}$	122 mph
$V_{\gamma_{max}}$ at SL	91 mph
$V_{R/C_{max}}$ at SL	112.5 mph
R/C at SL and 3300 lb	1200 fpm

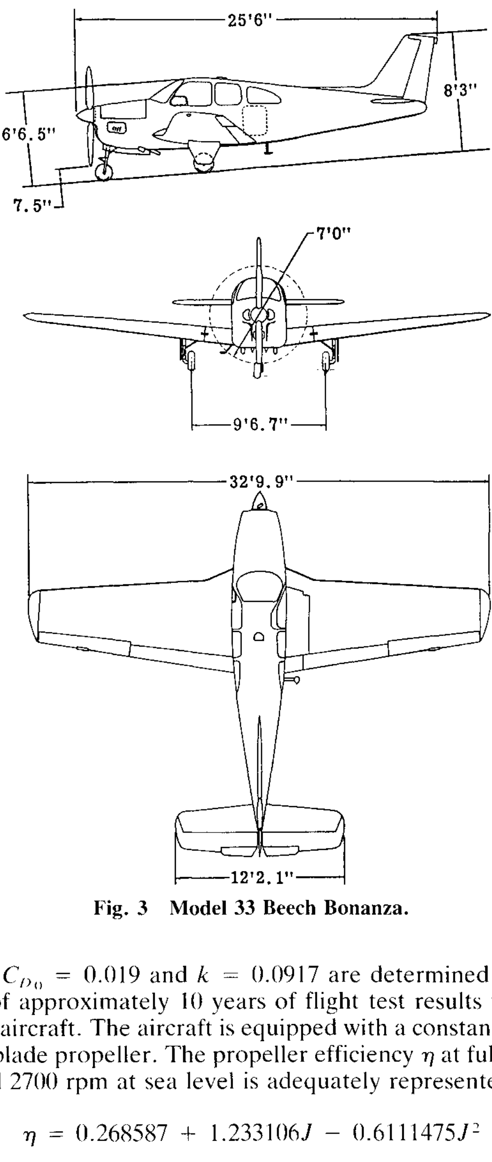

Fig. 3 Model 33 Beech Bonanza.

where $C_{D_0} = 0.019$ and $k = 0.0917$ are determined on the basis of approximately 10 years of flight test results for this model aircraft. The aircraft is equipped with a constant-speed three-blade propeller. The propeller efficiency η at full throttle and 2700 rpm at sea level is adequately represented by

$$\eta = 0.268587 + 1.233106J - 0.6111475J^2 \quad (14)$$

where $J = V/nd$ is the advance ratio with V in mph, n in rps, and d in ft.

At sea level at 3300 lbs gross weight the velocity for L/D_{max} is 122 mph, the velocity for maximum rate of climb $V_{R/C_{max}}$ is 112.5 mph, and the velocity for maximum climb angle $V_{\gamma_{max}}$ is 91 mph. The power-off stall velocity $V_{stall(clean)}$, gear and flaps retracted, is 72 mph.

Results

Footprint Plot

Using the simplified model discussed above, the effect of climb velocity, bank angle, failure altitude, and head- and crosswind velocity were investigated. The landing footprint, defined as the possible landing area from a given altitude, is determined by climbing to the failure altitude, executing a turn at the specified bank angle through a specified heading change, and then gliding at $V_{L/D_{max}}$ until touchdown. Heading changes from 0–360 deg were considered. The footprint curve illustrates the optional landing areas available upon engine failure.

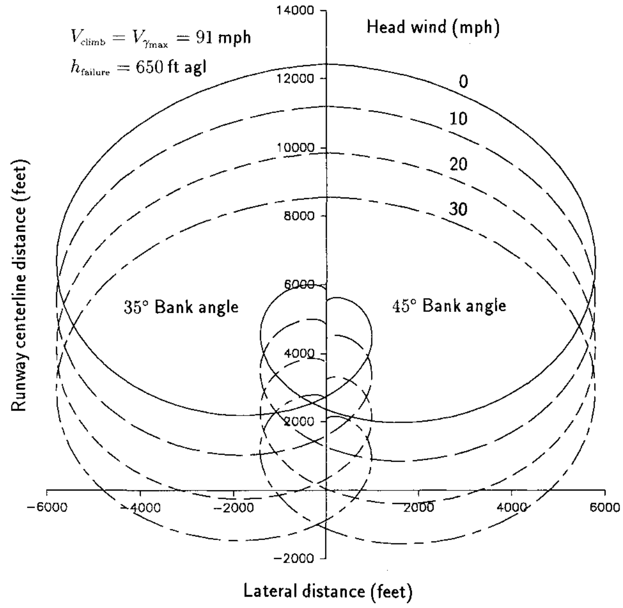

Fig. 4 Landing footprint after engine failure—head wind from 0 deg.

Figure 4 shows footprints for head winds of 0, 10, 20, and 30 mph, at bank angles of 35 and 45 deg for a climb velocity $V_{\gamma_{max}} = 91$ mph and a failure altitude of 650 ft agl. The velocity in the turn is assumed to be $V_{turning} = 1.05V_{stall\,(clean)}/\sqrt{\cos\phi}$, i.e., the unbanked stall velocity divided by $\sqrt{\cos\phi}$ multiplied by 1.05, the stall velocity factor. The intersection of the footprint curve at the top of the graph represents the touchdown distance from brake release if the aircraft glides straight ahead after engine failure. The second (numerically smallest) intersection of the footprint curve with the ordinate represents the length of runway required for the aircraft to touchdown on the departure end of the runway. The heading change is approximately 190–220 deg. Here the flight path is teardrop-shaped, as shown in Fig. 1. Notice that in each case the required runway length for the teardrop flight path is less for a 45-deg bank angle than for a 35-deg bank angle. Also notice that, as expected, an increase in the head wind velocity component results in a decrease in required runway length. Furthermore, for sufficiently large head wind velocities touchdown occurs beyond the takeoff end of the runway.

The third intersection of the curve with the ordinate represents the length of runway required for the aircraft to continuously turn through a full 360 deg and touchdown on the runway. Notice that the required runway length is considerably larger than for the teardrop flight path. Also notice, as expected, that the runway length required for a 35-deg bank angle is less than for a 45-deg bank angle because of the larger turn radius at 35 deg.

Figures 5 and 6 illustrate the effect of wind on the footprint. In Fig. 5 the wind is 45 deg from the runway heading, with velocities of 0, 10, 20, and 30 mph. The aircraft is turned into the wind using a 45-deg bank angle. As expected, the crosswind component pushes the footprint downwind. For this specific case the runway length required for touchdown on the departure end of the runway is increased by the decrease in the head wind velocity component, and is decreased by the slight reduction in required heading change. The net result is

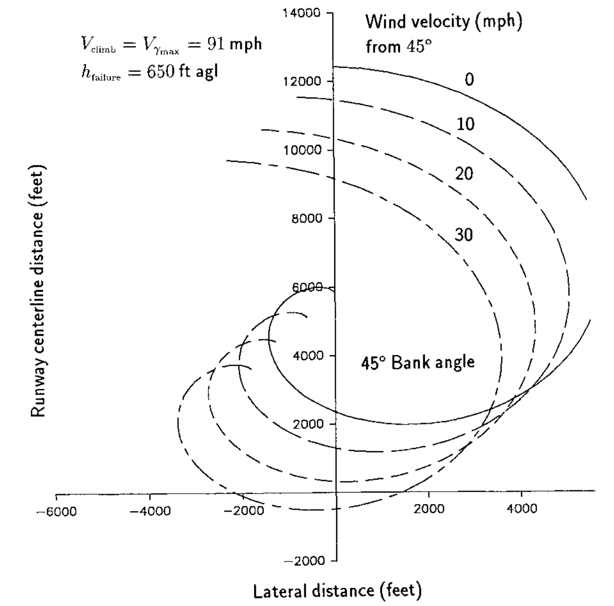

Fig. 5 Landing footprint after engine failure—wind from 45 deg, aircraft turned into the wind.

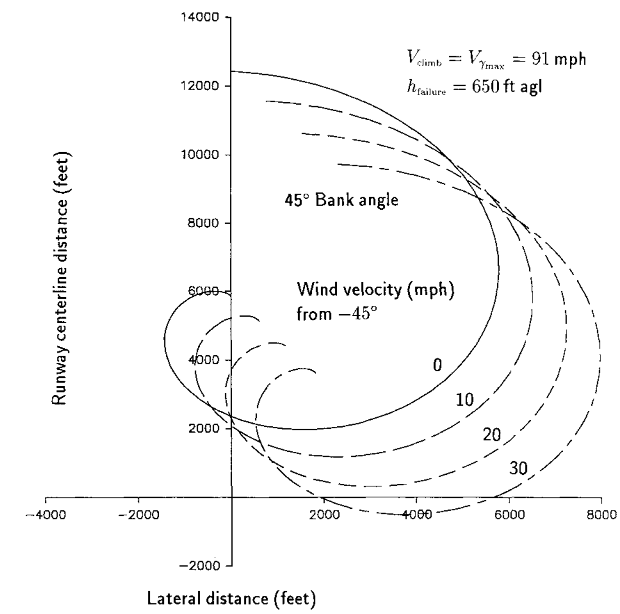

Fig. 6 Landing footprint after engine failure—wind from −45 deg, aircraft turned away from the wind.

an increase in the required runway length. Notice that in all cases the crosswind velocity component, combined with a full 360-deg heading change, results in the aircraft being blown beyond the runway centerline.

In Fig. 6 the aircraft is turned downwind, i.e., away from the crosswind component. Again, the runway length required for touchdown on the departure end of the runway is increased by the decrease in the head wind velocity component. However, and more importantly, the aircraft is now gliding into a head wind after completing the teardrop turn. The result is a significant increase in the required runway length for touchdown on the departure end of the runway. In fact, for the 30-mph wind, the aircraft cannot glide to the runway.

Effect of Climb Velocity, Failure Altitude, and Bank Angle

For a given failure altitude, two important parameters are how close the aircraft is to the end of the departure runway and the length of the departure runway. Frequently, the velocity for maximum rate of climb and a bank angle less than

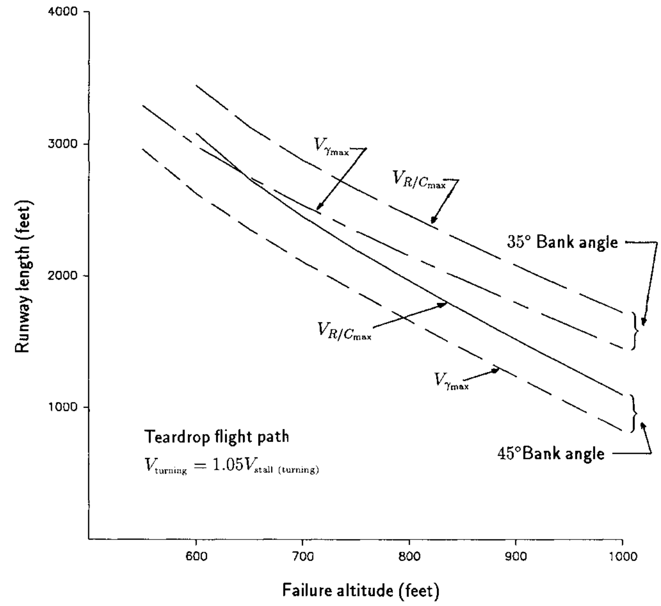

Fig. 7 Effect of failure altitude on required runway length—no wind.

45 deg is recommended for the initial climbout and turning phases. Figure 7 clearly shows that neither of these recommendations is optimum for successful completion of a turnback maneuver. Figure 7 shows the required runway length as a function of failure altitude for 35- and 45-deg bank angles, and for climbout at the velocity for maximum rate of climb and maximum climb angle. The velocity in the turn is 5% above the stall velocity in the turn, i.e., $V_{turning} = 1.05 V_{stall\,(clean)}/\sqrt{\cos\phi}$. No wind and a teardrop flight path are assumed.

Figure 7 shows that climbing out at $V_{R/C_{max}}$ vice $V_{\gamma max}$ for a failure altitude of 650 ft agl requires an additional 395 ft of runway when using either a 45- or 35-deg bank angle in the turn. Fundamentally, the aircraft is closer to the airport when engine failure occurs when using $V_{\gamma max}$ vice $V_{R/C_{max}}$ as a climbout velocity to a specific failure altitude.

Here it might be argued that time is a more appropriate variable for determining the engine failure point than altitude. Let us examine this question. It takes 3.5 s longer to climb to 650 ft at $V_{\gamma max}$ than at $V_{R/C_{max}}$. During that time the aircraft will increase its altitude by 77.4 ft. However, it will also be an additional 573 ft further downrange. To this must be added the additional downrange distance of 395 ft that results from using $V_{R/C_{max}}$ vice $V_{\gamma max}$. The total additional distance downrange using a climbout velocity of $V_{R/C_{max}}$ is now 968 ft. At $V_{L/D_{max}}$ the additional 77.4 ft of altitude results in an additional glide range of 817 ft, which results in an increase in the required runway length of 151 ft. Again, $V_{\gamma max}$ is a more optimum climbout velocity.

Examining Fig. 7, we further note that for the same failure altitude (650 ft) climbing out at $V_{\gamma max}$ and using a 35- vs a 45-deg bank angle in the turn requires an additional 380 ft of runway. Fundamentally, the larger bank angle results in a smaller turn radius. Hence, the aircraft is closer to the runway end at completion of the turn.

In both cases, using $V_{R/C_{max}}$ vs $V_{\gamma max}$ for the climbout velocity and using 35 vs 45 deg for the bank angle in the turn results in a 10–15% increase in the runway length required for touchdown on the departure runway.

Figure 7 also shows that the required runway length using 35 vs 45 deg for the bank angle in the turn decreases with decreasing failure altitude. This decrease is a result of the decreasing altitude available for gliding at $V_{L/D_{max}}$ after completion of the turn for the lower failure altitudes.

Effect of Bank Angle, Wind Direction, and Velocity

Figure 8 shows the effect of bank angle, wind direction, and velocity on the required runway length using a teardrop

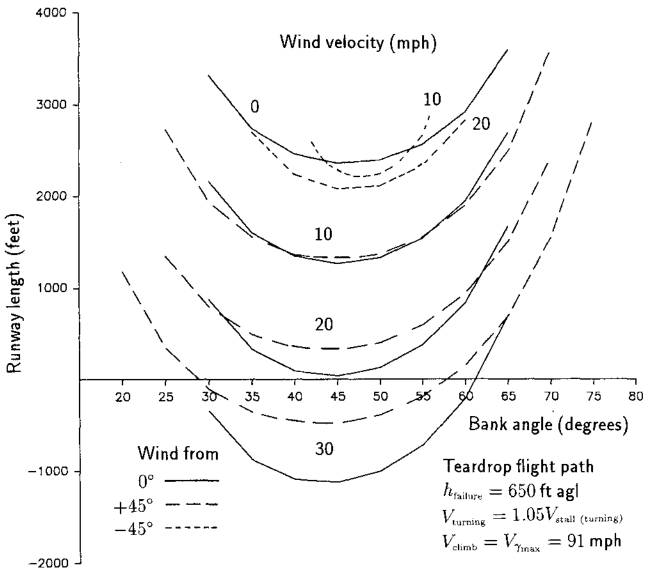

Fig. 8 Effect of wind direction and velocity on required runway length.

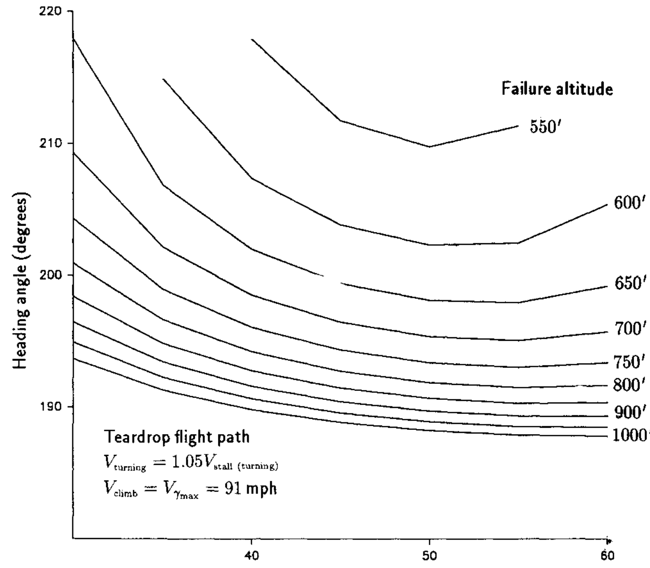

Fig. 9 Total heading change for a teardrop flight path—no wind.

flight path. For a direct head wind the minimum required runway length occurs for a 45-deg bank angle. Notice that varying the bank angle ±2–3 deg about 45 deg does not have a significant effect on the required runway length. However, significant variations in bank angle, e.g., ±10–15 deg about 45 deg, significantly increase the required runway length. As anticipated, for a pure head wind the required runway length decreases with increasing magnitude of the head wind. In fact, as previously indicated, the aircraft can be blown beyond the end of the runway.

Turning the aircraft into a wind from 45 deg relative to the runway heading (+45 deg), except for very low and very high bank angles, results in an increase in required runway length because of the decrease in the head wind velocity component. In addition, because of the crosswind effect the optimum bank angle is decreased slightly (≈1–3 deg), depending on the strength of the crosswind component.

As previously shown by the footprint graph of Fig. 6, turning the aircraft away from a wind from 45 deg relative to the runway heading (−45 deg) makes it impossible to land on the departure runway except for low head wind velocities. Figure 8 shows that this is also true for other bank angles, e.g., for a 20-mph wind from −45 deg, landing on the departure runway is only possible for bank angles of 42–56 deg. When no data are shown for a wind velocity from −45 deg, a landing on the departure runway is not possible. Note that a teardrop turnback is not possible for any bank angle for a 30-mph wind velocity. Analysis of the data shows that the optimum bank angle increases slightly (≈1–3 deg) because of the crosswind effect, e.g., for a 20-mph wind from −45 deg the optimum bank angle is 48 deg.

Required Heading Angle Change

Figure 9 shows the heading change required to intercept the departure runway at the minimum required length as a function of bank angle. The climbout velocity is $V_{\gamma_{max}}$. The velocity in the turn is 5% above the stall velocity in the turn, i.e., $V_{turning} = 1.05V_{stall\,(clean)}/\sqrt{\cos\phi}$. No wind and a teardrop flight path are assumed. The heading change decreases with increasing failure altitude and ranges from approximately 190–220 deg.

Effect of Turning Velocity

Figure 10 shows the effect on required runway length of increasing the velocity in the turn for failure altitudes of 650 and 1000 ft agl. For a failure altitude of 1000 ft agl, increasing the stall velocity factor from 1.05 to 1.6 increases the required runway length by a factor of nearly 4. For a failure altitude of 650 ft agl and stall velocity factors above approximately 1.3 the aircraft cannot return to the departure runway. Basically, this is because at these high velocities the turn radius is large enough that at the end of the turn the aircraft is displaced both laterally and along the runway centerline far enough that there is insufficient altitude remaining at the end of the turn to glide to the runway.

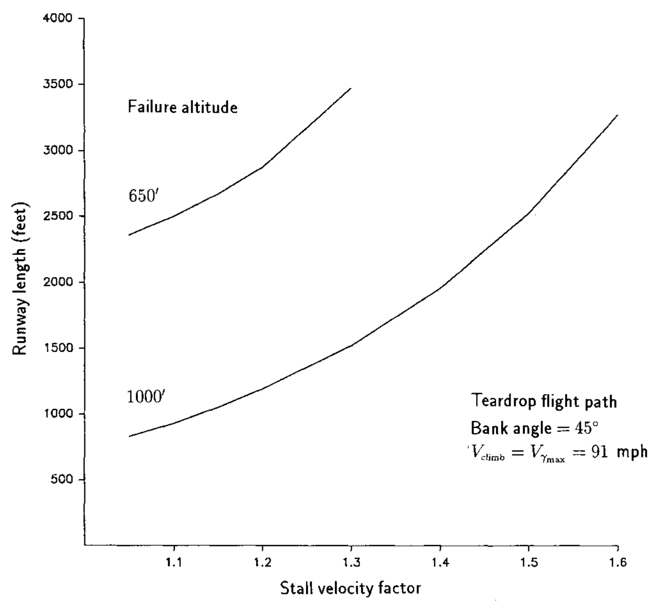

Fig. 10 Effect of stall velocity factor on runway length—no wind.

Frequently it is recommended that $V_{L/D_{max}}$ be maintained in the turn. For the Bonanza the velocity for L/D_{max} = 122 mph corresponds to a stall velocity factor of approximately 1.4. Examining Fig. 10 shows that the Bonanza cannot successfully execute a teardrop turnback maneuver from 650 ft agl. For a failure altitude of 1000 ft agl the required runway length for a successful maneuver increases by a factor of approximately 2.3.

Validity of the Simplified Model

Let us briefly look at the effect of the assumptions used for the simplified model. The aircraft POH shows that for a normal gross weight takeoff the liftoff speed is 80 mph and the speed at 50 ft is 90.5 mph. Notice that the speed at 50 ft is within $\frac{1}{2}$ mph of $V_{\gamma_{max}}$. Using the POH numbers for the takeoff distance over a 50-ft obstacle makes this effect negligible when using $V_{\gamma_{max}}$ for the steady climb. When using $V_{R/C_{max}}$ for the steady climb it is necessary for the aircraft to accelerate from 90.5 to 112.5 mph, which requires approximately 7 s. The decrease in rate of climb is 58 fpm, which results in a decrease in altitude gained of 7 ft and a decreased downrange distance of 113 ft. During the additional time required to reach the specified failure altitude, the aircraft travels an additional 52 ft downrange. Thus, the aircraft is estimated to be approximately 61 ft closer to the runway at engine failure than indicated by the simplified model.

The Model 33 Beech Bonanza has a roll rate in excess of 45 deg/s. Thus, approximately 1 s is required to roll into a 45-deg bank. Using a stall safety factor of 1.05, the required velocity in the turn is 89.9 mph, compared to $V_{\gamma_{max}} = 91.5$ mph and $V_{R/C_{max}} = 112.5$ mph. When climbing out at $V_{\gamma_{max}}$, the velocity in the turn is essentially the same as the climbout velocity. Hence, little or no altitude loss results when rolling into the turn and decreasing attitude to prevent stalling when climbing out at $V_{\gamma_{max}}$, whereas a small altitude gain may result for a climbout velocity of $V_{R/C_{max}}$.

Again, approximately 1 s is required to roll out of the 45 deg banked turn. Assuming the flight-path angle is increased 5 deg over that required to maintain a steady glide at 89.9 mph, it requires approximately 10 s to accelerate the aircraft from 89.9 mph to $V_{L/D_{max}} = 122$ mph. During the acceleration the aircraft travels approximately 110 ft less distance towards the runway than if it were flying at $V_{L/D_{max}}$. However, the average rate of sink is approximately 75 fpm less than if the aircraft were flying at $V_{L/D_{max}}$. Consequently, at the end of the acceleration phase the aircraft is approximately 12 ft higher, and at $V_{L/D_{max}}$ will glide an additional 127 ft. The small gain in distance towards the runway is thus on the order of 17 ft, a negligible amount. Hale[8] shows that, for other than the no-wind condition, flying the aircraft slower in a tail wind results in a more optimal glide. Thus, it appears that the simplified model is conservative.

From these results it is clear that the simplified model adequately represents the physics of the problem at least to a first approximation.

Comparison

Eckalbar[5] states "If you depart straight out in a 285-hp Bonanza climbing at 96 kts, you will be about 11,000 feet from your brake release point when you reach 1,000 feet agl." The recommended procedure assumes a steady climb at $V_{R/C_{max}}$. For these conditions the turn radius at $V_{turning} = 1.3V_{stall\,(clean)}/\sqrt{\cos\phi} = 103.4$ mph, and a 35-deg bank angle is approximately 1026 ft. Reference 5 gives the altitude loss during the 270/90-deg turn as 792 ft. Thus, at the completion of the 270/90-deg turn the aircraft is 8948 ft from the brake release point at an altitude of 208 ft. At $V_{L/D_{max}}$ from an altitude of 208 ft, the aircraft glides 2197 ft before contacting the ground. Thus, to land on the end of the departure runway requires a runway length of 6751 ft from brake release, i.e., a runway nearly 7000 ft long.

In contrast, the present model using a teardrop flight path, climbout at $V_{\gamma_{max}}$, and a $\phi = 45$ deg bank angle at a velocity of $V_{turning} = 1.05V_{stall\,(clean)}/\sqrt{\cos\phi} = 89.9$ mph, yields a required runway length of approximately 825 ft, a factor of more than 8 less than the procedure recommended by Eckalbar.[5] Using a 35-deg bank angle increases the required runway length to approximately 1450 ft, which is still a factor of nearly 5 less.

Can the Pilot Execute this Maneuver?

Based on statistics obtained from accident investigations conducted by the National Transportation Safety Board (NTSB),[9] the FAA, and most general aviation safety experts conclude that a low-level high bank angle turn is likely to result in a classic stall/spin accident with little chance of survival. Unfortunately, little attempt at validating the data base with respect to its completeness has been attempted. In fact, it is reasonable to conclude that the statistical accident/incident data base is incomplete. For example, if a turnback maneuver after engine failure is successfully completed or results in only minor damage, then generally no report is made to either the FAA or the NTSB. Furthermore, if a report is made, then it is likely that the report will stress the reason for the engine failure and not the maneuver that resulted in a successful on-airport landing. Consequently, the statistical data base is skewed towards failed attempts. Hence, conclusions drawn from analyses using these data bases are suspect at best.

Although the turnback maneuver is a high-performance edge of the envelop maneuver, there is good evidence that a well-trained pilot is capable of successfully performing it. Jett,[7] in a simulator study, showed that with minimal training over 90% of pilots with more than 100 h of flight time were able to successfully complete the maneuver using a 45-deg bank angle and a velocity of approximately $1.05V_{turning}$. The turnback maneuver is a standard required maneuver for the glider rating. An applicant for a glider rating must demonstrate, starting from an altitude of 200 ft agl, the ability to turn back to the departure runway when the tow rope breaks before qualifying for the rating. An unpowered single engine aircraft is simply a glider with a lower L/D ratio than a sailplane. Fundamentally, the only difference between a sailplane and an unpowered single engine aircraft is the critical altitude required to successfully complete the maneuver.

Conclusions

A simplified model of the turnback maneuver after engine failure during the takeoff climb segment has been developed. The model shows that optimum conditions for returning to the departure runway result from climbing at $V_{\gamma_{max}}$, executing a gliding turn through a 190–220-deg heading change at a 45-deg bank angle at 5% above the stall velocity in the turn using a teardrop-shaped flight path.

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