Dealing with engine failure on departure and the “impossible turn” decision

Evan Reed, cfievan@yahoo.com
Ed Williams
Flying Particles Club, Livermore, CA
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Aircraft: Hill / Europa XS (experimental)

CFI witness:
- "observed the airplane reach about 400 above ground level (agl) while approaching the end of the runway... The airplane then sunk about 100 feet in a level attitude... and as it reached about 300 feet agl, it made a hard left turn. The airplane continued to descend and reverse course. As the airplane came close to completing a 180-degree turn, the nose dove toward terrain. The airplane impacted in a near-vertical attitude and erupted into flames.

NTSB probable cause:
- The loss of engine power for an undetermined reason during the initial climb, and the pilot's failure to maintain adequate airspeed while attempting a return to runway maneuver, which resulted in a stall/spin.
The decision to turn back is controversial
Two options exist:

- Land off airport
  - Pros:
    - Minimal low and slow maneuvering required
    - Statistically more likely to walk away*
  - Cons:
    - Possible/likely aircraft damage
    - $ required for recovery
    - Attract unwanted attention from FAA, FPI, etc.
    - Suitable landing sites might not exist!

- Land on airport
  - Pros:
    - Minimize damage
    - Unlikely to attract attention from FAA
  - Cons:
    - Must maneuver airplane low and slow, with higher chance of fatal injury
    - Maybe have never done this before, especially in an emergency
    - May not be clear if this can be done beforehand

*Validity of statistics is uncertain; to be discussed later
KLVK 25R,L landing options

more options over here

road

fore!
There are flat non-runway areas on-field that are safe emergency landing spots (taxiways, grass areas, etc.)
KRHV 31R,L forced landing options are fewer than around KLVK
Success/failure of the turnback is determined by many factors:

- Altitude of aircraft at failure
- Airplane performance characteristics
- Human factors: pilot technique, reaction time, experience with turnback maneuver, total pilot experience
- Environmental factors: wind, runway length, density altitude
Turning with minimal altitude loss

- A turn with minimum loss of altitude (and minimum turn radius) is a key part of the teardrop maneuver.

- Altitude loss through a specified heading change is minimized with:
  - 45 bank angle
  - airspeed near stall

  - Note that aircraft stalls at higher indicated speed in vertically unaccelerated flight with 45 degrees of bank: \( \sim 1.2v_{\text{stall}} \)

(reproduced from Rogers)
C172 theoretical minimum altitude loss for 180 gliding turn occurs at 45 degrees of bank and accelerated stall speed

Altitude loss per radian can be determined by equating forces (assume steady flight) and assuming parabolic drag polar:

\[
\frac{\alpha v_g^2}{g \sin(2\theta)} \left[ \left( \frac{v}{v_g} \right)^4 \cos^2 \theta + 1 \right]
\]

This is valid for \(v > v_{\text{stall}}\) (accelerated).
\(\alpha\) = best glide ratio (1/9),
\(v_g\) = best glide speed (65 kts),
\(g\) = gravity acceleration,
\(\theta\) = bank angle

*steady flight assumption may be invalid for higher bank angles (much more than 45 degrees), making altitude loss more than depicted

There is no performance increase by using bank angles greater than 45 degrees. Increasing airspeed 10-20 kts above stall adds 100-150’ to descent.
Altitude loss in optimal turn varies with aircraft characteristics

At stall and 45 deg. bank (optimal conditions), altitude loss to make the turn back is proportional to:

\[
\frac{\alpha v_g^2}{g} \left[ \left( \frac{v_s}{v_g} \right)^4 + 1 \right]
\]

\(\alpha\) = best glide ratio,
\(v_g\) = best glide speed,
\(v_s\) = level flight stall speed,
\(g\) = gravity acceleration

- Glide angle \(\alpha\) might naively be considered to be the dominant performance spec, but \(v_g^2\) actually dominates the altitude loss for some airplanes with smaller \(\alpha\)
  - most piston singles have comparable glide ratios, but best glide speeds vary considerably, e.g. Bonanza (>100 kts) and C172 (65 kts)
- Flaps increase \(\alpha\) but decrease \(v_g\), might result in small performance increase (and might not).
  - Using flaps in the turn reduces glide performance after the turn is complete
  - Probably not a good idea to use them

Aircraft with larger glide speeds require more altitude to make the 180 turn.
Bonanza and Mooney pilots beware.
Rogers theoretical teardrop maneuver performance analysis

- Performance numbers for Beech Bonanza 33A
- Take-off and initial climb per POH distance and airspeeds
- Turn:
  - 45 degree bank angle
  - Airspeed 1.05 \( v_{\text{accelerated-stall}} \) in turn
- Post-turn glide:
  - Airspeed best glide \( (v_{L/D_{\text{max}}}) \)
- Transitions are assumed instantaneous
- No delay between engine failure and turn initiation

<table>
<thead>
<tr>
<th>Aircraft Characteristics</th>
<th>Beech Bonanza Model 33A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross weight</td>
<td>3300 lbs</td>
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<tr>
<td>Wing Area</td>
<td>181 ft(^2)</td>
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<tr>
<td>( L/D_{\text{max}} )</td>
<td>10.56</td>
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<tr>
<td>Power</td>
<td>285 bhp</td>
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<tr>
<td>Propeller</td>
<td>Constant Speed 3-blade</td>
</tr>
<tr>
<td>( V_{\text{cruise}} ) @ 65%</td>
<td>190 mph</td>
</tr>
<tr>
<td>( V_{\text{stall (clean)}} ) Power off</td>
<td>72 mph</td>
</tr>
<tr>
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<tr>
<td>( V_{L/D_{\text{max}}} )</td>
<td>122 mph</td>
</tr>
<tr>
<td>( V_{\gamma_{\text{max}}} ) @ SL</td>
<td>91 mph</td>
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<tr>
<td>( V_{R/C_{\text{max}}} ) @ SL</td>
<td>112.5 mph</td>
</tr>
<tr>
<td>( R/C ) @ SL &amp; 3300 lbs</td>
<td>1200 fps</td>
</tr>
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</table>
Bank angle and headwind impact turnback performance

- 45 degrees of bank yields gets you closer to your starting point, but 35 degrees is not much worse
- Overrun of runway during teardrop is possible for strong headwinds
Turning into a crosswind results in shorter runway length requirement.

**Turn away from crosswind**

- $V_{climb} = V_{\text{max}} = 91$ mph
- $h_{\text{failure}} = 650$ ft agl

**Turn into crosswind**

Wind velocity (mph) from 45°

- 0
- 10
- 20
- 30

- 45° Bank angle

reproduced from Rogers
45 degrees of bank and climbing at best angle require least runway length

Teardrop flight path

\[ V_{\text{turning}} = 1.05V_{\text{stall (turning)}} \]
Rogers analysis summary

- Max probability of successful turnback involves (in theory):
  - Initial climb at best angle speed
  - 45 degree bank during turn
  - Airspeed near stall in turn

- Human factors and broader risk mitigation strategies are neglected in this analysis
  - Successful completion of this maneuver may require practice
  - Climbing at best angle introduces new risks
  - Turning near stall speed at low altitude introduces new risks

Table 1  Aircraft Characteristics

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Human factors: Simulator study by Jett


- 28 pilots experience engine failure on takeoff at 500’ AGL in simulator representative of a “single-engined, light utility/sport aircraft”
  - Simulator exhibits partial motion
  - Early 1980s technology probably lacks realistic graphics, terrain, obstacles to crash into, etc.
- Experience ranges from 40 hour pilots to CFIs and 5000+ hour military pilots

Success criterion for landing off-airport:
- \(<2500\) fpm max descent rate
- \(<500\) fpm descent at touchdown
- wings within 5 degrees of level below 100’ AGL

Success criterion for turnbacks are the above plus:
- turn \(>175\) degrees above 100’ AGL
- maximum bank angle less than 55 degrees*

*Remember this one
Jett study: Flights #1 and #2

- **Flight #1:** Pilots were told to climb to 3,000’ AGL and await further instruction
  - Pilots were told to expect an emergency at some point during flight
  - Engine failed at 500’ AGL
- 85% of pilots landed straight ahead, no crashes
- Of the 15% that attempted a turn back, 2/3 crashed from steep bank/stall

- **Flight #2:** Pilots were told to expect engine failure at 500’ AGL
  - Pilots were told to handle it any way they wish
  - 90% pilots landed straight ahead, no crashes
  - Of the 10% that turned back, 50% crashed

100% of straight ahead landing attempts were successful.
>50% of turnbacks were considered crashes.
Jett study: Flights #3 and #4

- Flight 3:
  - Pilots were told to attempt 180 turn upon engine failure
  - 43% success rate
  - 85% of failures involved bank exceeding 55 degrees

- Flight 4:
  - Same as flight 3 but pilots directed to use 45 degrees of bank and airspeed just above stall
  - Overall success rate 75%
  - 10% unable to turnback successfully after 3 attempts

These flights suggest that success chance is improved by:
1) Experience with turnbacks and/or optimal technique use
2) Total flight time

Data reproduced from Jett
Jett study: Caveats to consider

- The scenario studied here was on the ragged edge of feasibility
  - This study involved turnbacks from 500’ AGL with an airplane that required about 340’ to do a 180 using optimal technique
  - These statistics are not likely to hold for turnbacks from higher or lower altitudes
- 100% of straight ahead landings were successful, but there were no terrain/obstacle issues in this study
- Bank angles greater than 55 degrees were defined as crashes
  - We know that there is no advantage to using more than 45 degrees of bank, but it would have been nice to see this demonstrated by this study rather than assumed
Effect of delayed turnback

- Unless you’re expecting it, there will be some time delay between engine failure and initiation of turnback maneuver.
- The delay time can impact probability of success.
- The advantages of minimizing the delay should be weighed against disadvantages of impulsive, poorly planned behavior.

Rogers data transformed by ~6 second delay (100’ descent) before turning

6 second delay increases runway length requirement by ~2100’ (2 x 6 second glide distance)

reproduced from Rogers
Lowering the psychological barrier to off-airport landings: What’s really going to happen after a successful off-airport landing?

- May attract attention from FAA, FPI
- Most likely, nothing bad will happen
  - May be responsible for club’s damage deductible
  - No one will criticize your decision to land straight ahead
- Worst case scenario (highly unlikely):
  - License suspended for some time period
  - Find another flying club

Ensuring that you and the plane are legal and insured before flying can minimize your hesitancy to land straight ahead.
Nall statistics

- Turnbacks are included in maneuvering category, with other types of accidents.
- Maneuvering accidents are comparable to some other categories.
- High fatality rate for maneuvering accidents reflects high danger level of this kind of accident.
- A comparative turnback study between glider and power pilots may shed light on the role of the turnback training that glider pilots receive.

2007 Nall report

### Accident Categories
**Single-Engine Fixed-Gear (SEF)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Total (%)</th>
<th>Fatal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preflight/Taxi</td>
<td>4.7 (33)</td>
<td>2.5 (3)</td>
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<tr>
<td>Takeoff/Climb</td>
<td>15.3 (127)</td>
<td>7.6 (54)</td>
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<td>Fuel Management</td>
<td>3.4 (4)</td>
<td>4.2 (30)</td>
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<td>Weather</td>
<td>13.6 (16)</td>
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<tr>
<td>Other Cruise</td>
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<tr>
<td>Descent/Approach</td>
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<td>12.7 (15)</td>
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<td>Go-Around</td>
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<td>Maneuvering</td>
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<td>10.5 (74)</td>
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<td>Landing</td>
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<td>9.3 (11)</td>
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<tr>
<td>Other</td>
<td>2.7 (19)</td>
<td></td>
</tr>
</tbody>
</table>
Turnbacks are included in maneuvering category, with other types of accidents.

While turnbacks do not dominate GA accident statistics, they get much attention in part due to their high fatality rate.

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**Lethality Index**

*Single-Engine Fixed-Gear (SEF)*

- Preflight/Taxi: 9.1%
- Takeoff/Climb: 14.2%
- Fuel Management: 7.4%
- Weather: 53.3%
- Other Cruise: 75.0%
- Descent/Approach: 46.9%
- Go-Around: 10.0%
- Maneuvering: 54.1%
- Landing: 1.7%
- Other: 57.9%
Turnbacks in C172 N73857

- All tests done at 3700’ DA, except 6000’ DA for #4
- All turns done with ~45 degrees bank
- Wind effects removed from data
- Test 1:
  - Climb vx, no delay before turn, near stall speed in turn
- Test 2:
  - Climb vy, 6 sec. delay before turn, 80 kts in turn
- Test 3:
  - Climb vy, 6 sec. delay before turn, 70 kts in turn
- Test 4:
  - Climb vy, 6 sec. delay before turn, 70 kts in turn, ~6000’ density altitude

Altitude loss ranges from 200-350’ for max performance to “safe” turns.

200’ altitude loss for maximum performance case (test 1) is close to theoretical prediction.
Some details about the data and extrapolations that follow

The time, altitude, and distance from the GPS “takeoff rotation” fix were recorded at points B, C, and D. Altitude of A and D are equal.

The maneuver was done into the wind. The time to arrive at point D enabled calculation of wind speed effects on point D location. Extrapolations to failure altitudes other than those flown were accomplished assuming the altitude change is compensated by the climb and glide segments, i.e., the altitude required for the turn is independent of failure altitude.

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<td>80</td>
<td>70</td>
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</table>
Turnbacks from 1000’ AGL in C172 N73857

- Test 1: Climb vx, no delay before turn, near stall speed in turn
- Test 2: Climb vy, 6 sec. delay before turn, 80 kts in turn
- Test 3: Climb vy, 6 sec. delay before turn, 70 kts in turn
- Test 4: Climb vy, 6 sec. Delay before turn, 70 kts in turn, ~6000’ density altitude

Return possible for all wind speeds. S-turns required in many cases. Most challenging for high density altitude case.

Negative values correspond to overshooting the runway.

Landing point from engine failure at 1000’ AGL

Distance from takeoff rotation point (NM)

-3 -2 -1 0 1

0 wind
10 kt headwind
20 kt headwind
30 kt headwind
Glide ratios measured are substantially lower than POH value of 1/9. Reason for this is unclear.

Glide ratios are all greater than climb ratios for all test cases => climb angle is greater than glide angle.

- Test 1: Climb vx, no delay before turn, near stall speed in turn
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- Test 4: Climb vy, 6 sec. Delay before turn, 70 kts in turn, ~6000’ density altitude
Successful turnback rule of thumb

You can turnback if: 1) you height when crossing the departure end of the runway exceeds the altitude required to make the turn, AND 2) Climb ratio is more than glide ratio.

Climb ratio = glide ratio.  
Success

Climb ratio > glide ratio.  
Failure

For 10:1 glide ratio airplane, the latter condition can be determined by comparing airspeed (kts) to vertical speed/10 (fpm).
E.G., turnback can be made if vertical speed/10 (fpm) > airspeed (kts).

Turning back becomes impossible as climb ratio decreases (e.g. density altitude) => turning back may be impossible regardless of altitude for high density altitude.
Extrapolated return point from C172 N73857 data, test 1: maximum performance

- Test 1: Climb vx, no delay before turn, near stall speed in turn

For this MAXIMUM PERFORMANCE case, 600’ AGL is minimum turnback altitude for most runways with no wind (3700’ density altitude).
Test 2: Climb \( vy \), 6 sec. delay before turn, 80 kts in turn, 3700’ density altitude

For this relatively sloppy case, 900’ AGL is minimum turnback altitude for most runways with no wind (3700’ density altitude.)
Turnback video in C172 N73857

- See it at: http://www.youtube.com/watch?v=SNgoOFq87aY
- Climb at best rate (76 kts)
- Engine fail at 800’ AGL, ~1000 density altitude
- 6 second delay before turn initiated
- 40-45 degrees bank with 75 kts airspeed (no buzzer)
- 7 kt headwind on surface, probably 10-20 kts aloft
- Return to runway possible, s-turns required to avoid overrun
- Results of this flight are in reasonable agreement with extrapolated results
Practical tips

- Turn crosswind at 500’
  - You probably can’t turn back before this and if you need to on crosswind, you’ll already be halfway through the turn

- Decide on a personal strategy while on the ground
  - Consider the number of different models of aircraft you fly and your knowledge of the critical altitudes for those aircraft
  - Your experience with the turnback maneuver
  - Your overall experience level (remember Jett study)

- If you decide to turn back:
  - Keep bank angle 35-45 degrees
    - Theory and Jett simulator study show that 45 degrees or less is both safest and most effective
  - A 10-20 kt airspeed safety margin over stall speed can be purchased with a 100-150’ increase in turn altitude for a C172
  - Be prepared for possible s-turns and potential overrun