# WHAT LIES BELOW

## Plan to avoid the rocks during an emergency descent.

BY PATRICK CHILES

Flying over mountains on a clear day, it is common to see passengers craning their necks toward the cabin windows to take in the scenery. Although the view can be spectacular from such a vantage point, it also shows the hazards that lie below. While our passengers enjoy the sights that break up the monotony of a long flight, pilots must be mindful of what it would take to avoid the hazards if need be. Ensuring safe terrain clearance is a basic aspect of route planning, but it frequently is overlooked or oversimplified.

Checking the minimum en-route altitudes (MEAs) on the airway chart is easy but does not tell the full story. Standards for adequate terrain clearance are similar among regulatory agencies, but concepts such as *track widths*, *net drift-down flight paths* and *depressurized profiles* will further influence an air carrier's terrain-avoidance planning.

As with most topics involving airplane performance, this one can be reduced to a simple question: What are the worst possible points en route to lose an engine or cabin pressure, and what happens next?

### Engine-Out Regulations

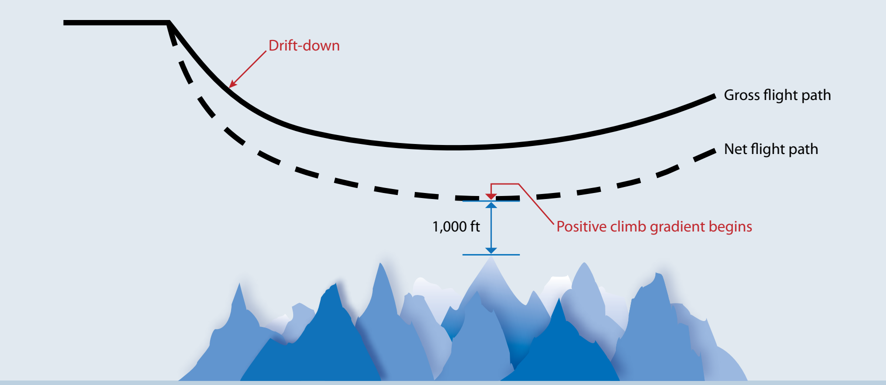
The International Civil Aviation Organization (ICAO), the European Aviation Safety Agency (EASA), the Joint Aviation Authorities (JAA) and the U.S. Federal Aviation Administration (FAA) have the same basic engine-out performance standards for en route terrain avoidance. The standards apply when route segments have terrain-limited MEAs that are higher than the airplane's one-engine-inoperative (OEI) service ceiling.

The standards require that within a specified lateral distance of the intended en route track, a given flight must have at least 2,000 ft of vertical clearance from terrain during the engine-out drift-down to the OEI service ceiling or to an airway segment with a lower MEA and 1,000 ft of vertical clearance in the level-off segment. Moreover, the airplane's OEI performance must be adequate to achieve a positive climb gradient when the airplane is 1,500 ft above the airport at which it would be landed following an engine failure. The flight cannot be initiated at a takeoff weight that would not allow the airplane to meet these minimum performance standards en route.

The specified lateral distance, or track width, for obstacle clearance is where the regulatory bodies differ. ICAO and the FAA specify 4.3 nm (8.0 km) on either side of the intended track.[1,2] JAA specifies 5.0 nm (9.3 km).[3] Track width differences adopted by other civil aviation authorities include the Civil Aviation Administration of China's 13.5 nm (25 km).

The harmonized EASA and FAA transport category airplane certification standards require en route drift-down flight paths to be determined using the most conservative airplane configuration, including the most unfavorable center of gravity and with the critical engine(s) inoperative.[4,5] Airplane manufacturers are required to apply decrements to the actual, or *gross*, en route flight paths to

**Drift-Down Flight Paths**



Source: Patrick Chiles

Figure 1

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establish the *net* drift-down flight paths (Figure 1). The engine-out net flight path represents actual climb performance — which is negative above the OEI service ceiling — reduced by a gradient of 1.1 percent for two-engine airplanes, 1.4 percent for three-engine airplanes and 1.6 percent for four-engine airplanes. Moreover, three- and four-engine airplanes have two-engines-inoperative requirements that reduce actual climb performance by a gradient of 0.3 percent and 0.5 percent, respectively.

Because these decrements are percentages applied over distance and time, the margin between gross and net performance increases throughout the drift-down segment. A comparison of the net level-off heights with the gross level-off heights published in the airplane performance manual will reveal a significant difference. While this should provide us some comfort, it is important to differentiate between the two when planning a route. Mistakenly using gross performance data could lead to incorrect planning solutions and erase the intended safety margins built into the regulations.

Given the high performance of current production jet transports, there are only a few areas of the world where terrain clearance can be problematic: the Andes in South America, the Himalayas between India and Tibet, and the Hindu Kush regions of Central Asia. However, older turbojet airplanes might have trouble clearing the North American Rockies or the European Alps with one engine inoperative.

Offered here are some general techniques to develop en route engine-out terrain-escape paths. The techniques are by no means all-inclusive or model-specific. It is the responsibility of the individual air carrier, charter company or corporate aviation department to devise a plan that best suits its operations and equipment.

## Working Backward

The simplest way to check engine-out terrain clearance is to begin at the desired end condition — net level-off height — and work backward. If, at any given step, there is adequate terrain clearance, the analysis is complete. If not, it is necessary to move on to the next step until clearance standards are met.

The next step begins with a check of level-off height resulting from the planned takeoff weight, using the net level-off chart provided in the airplane flight manual (AFM) or performance manual. The chart depicts regulatory terrain clearance as a function of airplane weight and ambient temperature. If the net level-off height exceeds the highest terrain elevation plus 1,000 ft along the planned route, then the flight is unquestionably safe. A very easy way to check this is by planning the flight to remain on published airways and comparing the MEAs with the net level-off height. If the minimum en route altitudes are too high, use the depicted minimum off-route altitudes (MORAs), because MEAs are not necessarily based only on terrain clearance. However, the solution may not end there.

Continuing to work backward, the analysis progressively becomes more complicated. Suppose the minimum clearance altitude exceeds the net level-off height at the planned takeoff weight? In that case, it is necessary to calculate the planned fuel burn-off and determine the airplane's weight when it enters the area of terrain. If this shows that the clearance altitude does not exceed net level-off height, the flight is safe. The maximum weight when entering that area should be added to the expected fuel-burn weight to determine maximum takeoff weight for terrain clearance. If set at a fixed value for simplicity, the most adverse temperature should be assumed; otherwise, the actual maximum drift-down weight should be determined for each flight.

If, however, the expected fuel burn-off will not shed enough weight for terrain clearance en route, an obvious solution is to reduce takeoff weight by trimming payload, which means less revenue, or carrying less fuel, which might mean an en route fuel stop, adding time and expense.

## Drift-Down Flight Path

With thorough route planning, reducing takeoff weight should be an option of last resort. Recall that net level-off height is not the only limiting factor; drift-down also must be considered, and they are not exactly the same thing. Level-off is just the end of the drift-down segment. For some airplanes, that segment can be quite long. An engine failure does not result in the airplane dropping straight down to the level-off height; it takes some time and distance to get there. In many cases, the descent path may be long enough and sufficiently shallow to get beyond critical terrain.

The correlation is obvious when an engine-out drift-down flight path diagram, such as the one shown in Figure 1, is compared with an airplane's net drift-down chart, such as the example shown in Figure 2. It helps to visualize the chart as a graphic depiction of the actual descent path adjusted for the required net flight path decrements. An airplane at any given weight will follow its own curve resembling the diagram in Figure 1, and the associated top of the curve in Figure 2 will move farther across the chart as weight is reduced. This represents how much distance the airplane can cover at cruise altitude while airspeed is bled off. At some point, the airplane inevitably "starts downhill." Typically, net drift-down charts are constructed so that the user can find the elapsed time and/or ground distance adjusted for wind. Some airplanes could easily take nearly an hour to reach the level-off height; in that time, they could cover about 300 nm (556 km), which might be enough to safely get out of the critical area.

As with takeoff performance, it pays to know the carrier's underlying operating assumptions. The manufacturer's data often assumes a maximum lift-to-drag ratio descent with some residual climb gradient at level-off. Some carriers elect to use drift-down profiles consistent with their extended operations (ETOPS) policies and trade some of that altitude capability for speed. There are also more options at the bottom of the descent path, such as trading speed for altitude as fuel is burned off or descending further to immediately accelerate to the selected engine-out speed (Figure 3).

Given these choices, it is still possible that the illustrated descent case may not be enough. A good example is a direct route between Panama City, Panama, and Buenos Aires, Argentina, that bisects the Andes, where minimum obstruction clearance altitudes (MOCAs) exceed 25,000 ft.

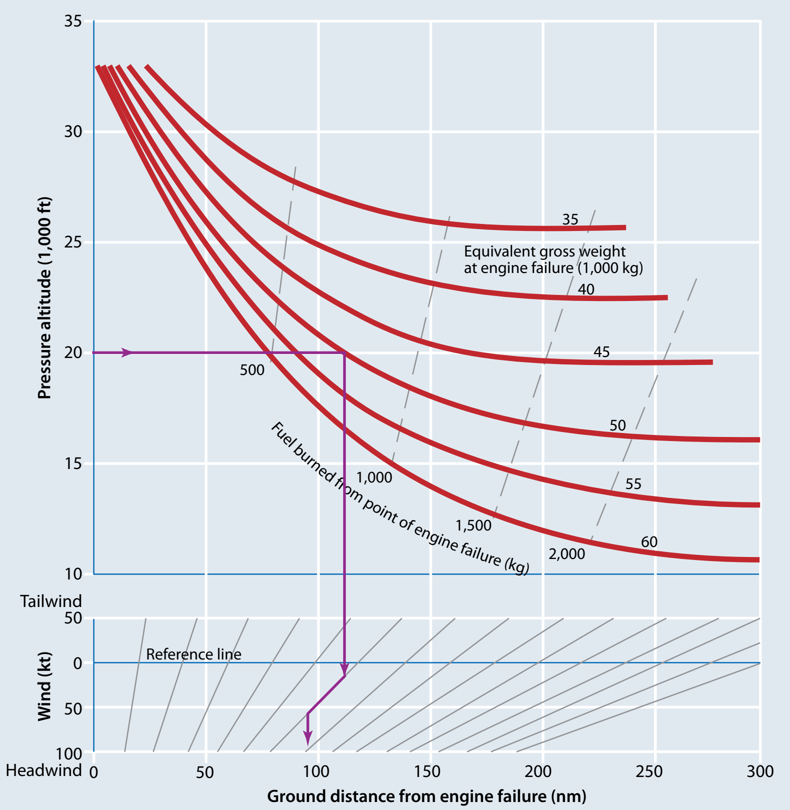
## Equal-Time Points

A quick method to check your drift-down flight path is to calculate equal-time points (ETPs) for alternates selected at either end of the mountain range. If an ETP drift-down path does not violate any published obstacle-clearance altitudes, the flight is safe to proceed as planned at that weight and temperature condition.

During a route-planning exercise, it is important to consider prevailing winds for the time of year — not to be confused with the "zero wind" condition used for ETOPS planning (*ASW*, 3/07, p. 12). Winds will affect ETP location and any subsequent critical-path analysis. Specifically, the following must be considered:

- Net performance — drift-down/level-off with the required gradient decrements;
- Expected en route ambient temperatures;

**Net Drift-Down Profiles**



**Note:** In this example, equivalent gross weight is actual gross weight at time of engine failure corrected for ambient temperature and use of anti-icing systems.

Source: Patrick Chiles

Figure 2

- Adverse winds;

- Fuel and oil consumption, with enough fuel remaining after reaching the intended airport for 15 minutes of flight at cruise thrust; and,

- Fuel jettison.

Also, three- and four-engine airplanes have a different standard to meet than twins: No terrain analysis is required if suitable airports are available within 90 minutes of all points along the route; if not, a two-engine-out scenario must be evaluated.

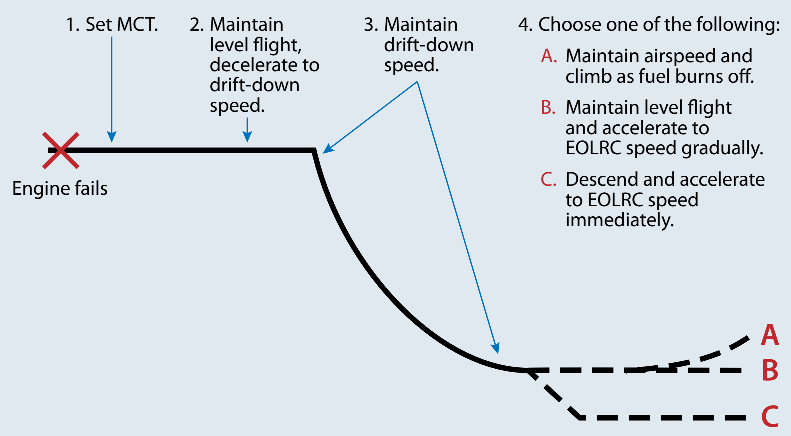
If the calculation is performed manually, the terrain-clearance path should be a great circle drawn from the ETP to each alternate. Terrain within the specified track width, including any turn-backs, also must be considered. More commonly, the calculation will be done using flight-planning software. As with the carrier's operating assumptions, it is crucial to understand the software's calculation methods. For instance, how is drift-down start weight determined? Does it use AFM-derived net drift-down? Does it assume a residual climb rate or acceleration segment? Are the MOCAs considered in the calculation consistent with the en route charts being used? These calculation assumptions must be compared with the carrier's desired methods, consistent with the appropriate regulations.

Scheduled airlines have a distinct advantage in this regard, because routes typically are analyzed by an engineering staff or a working group of pilots and dispatchers well in advance of the actual flights. Unscheduled charter and corporate operators flying the same routes typically have less time to prepare and often must rely on their flight-planning services for assistance.

## Escape Areas

At this point in the analysis, if a flight is still too heavy to maintain safe engine-out terrain clearance, the options are more limited. If other airways can be found around the area,

**Drift-Down Options**

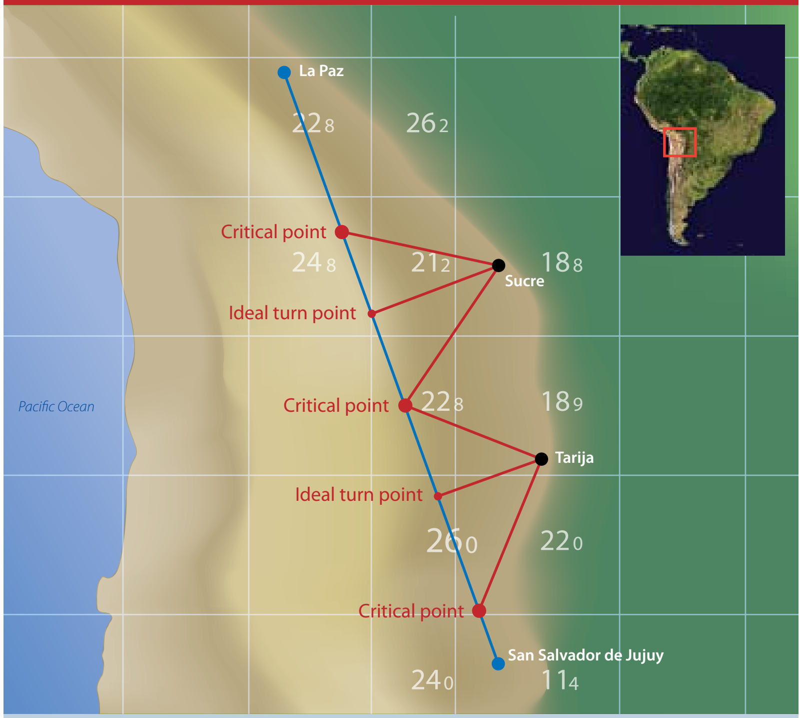


EOLRC = engine-out long-range cruise
MCT = maximum continuous thrust

Source: Patrick Chiles

Figure 3

**Escape Areas**



Source: Patrick Chiles

**Figure 4**

the penalty of flying a greater distance may be offset by fewer terrain problems. Another alternative to reducing fuel or payload is to create "alternate availability areas" — or "escape areas" — along sections of the route. Escape areas may not completely eliminate the need to reduce weight, but they can at least limit the impact on operations.

Each escape area allows the airplane, following an engine failure at any point along a designated section of the route, to drift down safely from cruise altitude and land at an alternate airport.

The alternate airports ideally should be located somewhat perpendicular to the intended route, preferably in less hostile terrain and at relatively short distances within the drift-down flight path. Once the alternates have been identified, "critical points" can be established. A maximum airplane weight that will maintain drift-down and level-off clearance should be determined for each critical point.

The concept is simple, but the planning and execution can be complex. There could be multiple iterations of the same escape area, depending on the entry path, airplane weight, wind and temperature. Accurate terrain information is crucial, and commonly used en route charts may not provide enough detail. A better source is U.S. Defense Mapping Agency operational navigation charts, or "ONC charts," which provide excellent terrain detail. They depict airports and special-use airspace — but not airways. Thus, it is necessary to locate the lat/long coordinates of the desired route and plot them manually on an ONC chart before working out escape areas.

Here is the technique for putting this concept to work: For each of the selected alternates, the "ideal" turn point is established; the direct flight path from this ideal turn point to the alternate is perpendicular to the route and, thus, comprises the shortest distance from the route to the alternate. After the ideal turn point is established, other critical points before and after the ideal turn point are determined. This will create a triangular escape area, with the apex being the off-route alternate and the other corners being the designated critical points on the desired route. Depending on the distance covered during the flight, it may be necessary to create multiple off-track escape areas, which would be laid out as consecutive triangles. Within each triangle, all terrain must be examined in great detail and compared with the drift-down net-flight-path charts for the correct airplane weight.

For example, escape areas created along the route from La Paz, Bolivia, to San Salvador de Jujuy, Argentina, are shown in Figure 4. The airway between these cities, UA558, has an MEA of 24,500 ft.

Information on en route escape areas should be provided as clearly as possible to the flight crews. This could be done as part of the normal flight dispatch briefing or by including a list of predetermined weights and critical points in the company operations manual. It should certainly be part of an operator's training program.

## Turn-Back Points

An alternative to constructing multiple escape areas is to designate turn-back points. Assuming that at least one escape area has been created, the first critical point for the escape area can be considered a decision point. If the airplane loses an engine before reaching the decision point and is over the maximum weight designated for that critical point, the crew should turn back along the airway and proceed to the nearest alternate.

However, turn performance should be considered, and bank angles minimized. The gradient loss in an engine-out flight path will be greater if a turn-back is included in the escape procedure. In addition, the terrain in the turn path must be analyzed. The direction of the turn also can have some effect on terrain clearance; turning into the area with the lowest MORA is recommended. Also, a teardrop course reversal can limit exposure to surrounding terrain, depending on the turn-back point.

Constructing terrain-escape paths is rigorous work, but it provides better alternatives than reducing payload or adding a fuel stop to reduce takeoff weight. There are some areas where off-track escape routes are mandatory. Most notably, the L888 airway in southern China is very close to the Himalayan range. In addition to showing that it meets Future Air Navigation System (FANS) requirements, a carrier must submit its terrain-escape plans to China Civil Air before gaining approval to use that airway. Considering that L888 is one of the most efficient routes between Southeast Asia and Western Europe, it is certainly worth the effort to break out the topographic charts and the AFM.

## Rarefied Air

Besides engine-failure scenarios, en route terrain-avoidance planning must consider loss of cabin pressure. Some kind of escape path likely will be necessary because less time will be available to descend to a safe altitude. Depending on the type of emergency oxygen system aboard the airplane, the crew might have as little as 12 minutes to get down to a safe altitude — at worst, 10,000 ft.

Some airliners and many business jets have relatively high-capacity gaseous emergency oxygen systems. In most airliners, however, emergency oxygen for the passengers is provided by solid chemical systems. Commonly known as "burner systems" because of the heat produced during the chemical reaction, they typically provide only 12, 15 or 22 minutes of oxygen. A carrier operating large airplanes over high terrain should opt for the higher-capacity gaseous emergency oxygen system, if available; the associated tanks and plumbing add weight, but the increased time at altitude allows greater distance for terrain-escape paths.

Because the physiological needs of crew and passengers vary with altitude, minimum oxygen flow must be considered in a depressurized profile. Once an emergency descent speed is determined, the distance covered during the appropriate time limit is simple to determine. If the airplane has a low-capacity oxygen system, the emergency descent profile could conflict with terrain.

More off-track escape routes often are needed for depressurization scenarios than for engine-outs. The techniques for developing the escape routes are similar to the engine-out analyses, with the difference being the consideration of emergency oxygen capacity versus time/distance, instead of single-engine performance.

One apparent advantage to the depressurization scenario is that it is assumed to involve all engines operative; thus, higher speeds are possible. However, if a depressurization does occur en route, and the pilots suspect that it was caused by a structural failure, they would have to fly the airplane at a lower speed than planned and limit maneuvering loads. This could substantially limit their options for escaping terrain.

Proper planning for en route terrain avoidance can be easy to overlook, or it may be done "sight unseen" to the flight crew. As with any performance consideration, there are a number of choices available to the operator that should be made known to the flight crew. When the passengers begin to enjoy the mountain scenery, the flight crew should know what precautions and actions will keep them safely above the rocks below.●

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## Notes

1. ICAO. *Annex 6, Part I: International Commercial Air Transport — Aeroplanes.* Attachment C, *Aeroplane Performance Operating Limitations.*
2. FAA. U.S. Federal Aviation Regulations (FARs) Part 121, *Operating Requirements: Domestic, Flag and Supplemental Operations*, Sections 121.191 and 121.193; and FARs Part 135, *Operating Requirements: Commuter and On Demand Operations*, Sections 135.381 and 135.383.
3. JAA. Joint Aviation Requirements — Operations 1, *Commercial Air Transportation (Aeroplanes).* JAR-OPS 1.500, "En-route — One Engine Inoperative," and JAR-OPS 1.505, "En-route — Aeroplanes With Three or More Engines, Two Engines Inoperative."
4. EASA. CS-25, *Certification Specification for Large Aeroplanes.* CS 25.123, "En-route flight paths."
5. FAA. FARs Part 25, *Airworthiness Standards: Transport Category Airplanes*, Section 25.123, "En route flight paths."