When Less Is More

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Reduced-thrust takeoffs offer safety benefits, as well as economic benefits.

Engine and airframe manufacturers for decades have cited the direct relationship between engine wear and high exhaust gas temperature (EGT) in recommending that operators use less than maximum takeoff thrust whenever possible. While the cost benefits of reduced-thrust takeoffs are thoroughly documented, the safety benefits are not as well understood.

Thus, there is a common perception that using reduced thrust is less safe than taking off with full-rated power. Undoubtedly, maximum

Sample Takeoff Data

Outside Air Temperature	Maximum Takeoff Weight	V_1	V_R	V_2
35˚C	147,900 lb	129 kt	129 kt	136 kt
30˚C	153,000 lb	130 kt	130 kt	138 kt
20˚C	155,500 lb	131 kt	131 kt	139 kt
10˚C	157,000 lb	132 kt	132 kt	140 kt

V_1 = The maximum speed in the takeoff at which the pilot must take the first action (e.g., apply brakes, reduce thrust, deploy speed brakes) to stop the airplane within the accelerate-stop distance. It also is the minimum speed in the takeoff, following a failure of the critical engine at V_{EF}, at which the pilot can continue the takeoff and achieve the required height above the takeoff surface within the takeoff distance. (V_{EF} is the speed at which the critical engine is assumed during certification to fail during takeoff.)

V_R = Rotation speed

V_2 = Takeoff safety speed

Sources: Patrick Chiles, U.S. Federal Aviation Administration

Table 1

thrust will provide maximum takeoff performance. However, using reduced thrust does not mean that safety margins are reduced. There actually is a significant safety benefit: By increasing engine life, reduced-thrust takeoffs reduce the chances of engine failure.

A key factor in this concept is that turbine engines are guaranteed to provide maximum thrust at and below a specific ambient temperature — 30 degrees C for the CFM International CFM56-7B series, for example. At higher temperatures, maximum available thrust decreases because of decreased air density.

Typical runway-analysis tables, created either by the operator or by a qualified vendor, show a range of ambient temperatures and the maximum takeoff weights and the performance data (V-speeds) applicable to those temperatures (Table 1). In modern airplanes, takeoff thrust settings are computed by the flight management computer (FMC), based on programmed or pilot-selected temperatures or weights.

There are two methods for conducting reduced-thrust takeoffs: the fixed derate method and the flex thrust, or assumed temperature, method.

Fixed derate thrust settings are lower than the maximum flat-rated thrust setting for the engine. The CFM56-7B27, for example, has a maximum thrust rating of 27,300 lb (121 kN), with optional fixed derates at 22,000 lb (98 kN), 24,000 lb (107 kN) and 26,000 lb (116 kN). These settings are pre-programmed in the FMC and, if allowed by the operator, can be selected by the pilot when conditions permit.

The flex thrust/assumed temperature method employs an alternate thrust setting that is applicable to the highest ambient temperature at which the airplane could meet performance requirements at its actual takeoff weight.

Flex thrust essentially takes advantage of the spread between the actual weight at the actual temperature and whatever the maximum temperature for that weight would be. Assume, for example, that we are preparing for takeoff from an airport with an outside air temperature (OAT) of 10 degrees C. Our runway analysis data show that the maximum takeoff weight at this temperature is 157,000 lb (Table 1). But, because our aircraft weighs only 147,000 lb, we can move up the data columns until we find the maximum OAT for our actual weight, which is 35 degrees C.

This becomes our "assumed" temperature, which we enter into the FMC. In this case, the reduction in the takeoff thrust setting could be on the order of 3.5 percent N_1 (low-pressure rotor speed) — from 99.9 percent to 96.4 percent, which is set when takeoff/go-around power is selected.

The flex thrust/assumed temperature method also allows pilots to advance the thrust levers to achieve the full rated thrust setting at any stage of the takeoff, if necessary. This is not an option when using a fixed derate setting.

Effect of True Airspeed

Pilots who are skeptical about reduced-thrust takeoffs often sense that something very important is being taken away. However, there is absolutely no loss of any necessary performance margins involving field length, screen height,[1] climb or obstacle clearance. If the airplane's weight and power setting satisfied the certification standards at the higher temperature, then they certainly will do so at the lower temperature.

Although the takeoff speeds used by the flight crew are indicated airspeeds, actual performance is determined by true airspeed, which is a function of air density. Because we are operating at an actual temperature that is lower than the assumed maximum, true airspeed likewise will be lower.

Because of this true-airspeed effect, we enjoy a great deal of cushion between what the airplane must do and what it actually is doing. We are, in reality, using less runway and achieving a higher climb gradient, or obstacle-clearance margin, than if the ambient temperature was at the maximum for that same weight. Depending on conditions, the effect can be considerable — on the order of several hundred feet in field length. The benefit increases as the difference between the actual and the assumed temperatures increases.

Inside the Engine

Performance margins are not the entire story. Reduced-thrust takeoffs trade some excess capability for reduced engine wear. Operating temperatures, turbine speeds and overall stress levels are lower, and the engine is less likely to fail. This is especially important when you consider that the possibility of engine failure is the basis for all those takeoff performance margins in the first place.

The closely held studies by engine manufacturers are based primarily on fixed derate thrust data because operators typically do not report assumed temperature thrust data. However, equivalent temperature levels using assumed temperature techniques can be favorably compared to the results.

Component wear in the hot section, particularly the high-pressure turbine, can be dramatically improved. One available GE Aviation study of failure modes in the CF6-80 indicated that regular use of the maximum 25 percent fixed derate resulted in a near order-of-magnitude increase in cycles to failure — from 1,000-2,000 cycles to 5,000-10,000 cycles. This study identified thrust derate as the "most important factor in reducing turbine blade failures and deterioration."[2]

Reducing EGT has been tied directly to improved engine wear and time-on-wing maintenance intervals. EGT deterioration, a major factor in engine removal and overhaul, also has been shown to be retarded by reduced thrust. Related deterioration of fuel flow also is countered by reduced-thrust operations. According to the GE study, each 10 degrees C of EGT deterioration translates to a 1 percent fuel-flow deterioration. Limiting this effect has obvious advantages in maintaining a higher level of specific mileage for a given amount of on-board fuel.

Manufacturers approximate the effects of engine use against the engine's designed operating life through severity analysis, which considers the total picture of degraded performance, rotating parts life and parts deterioration and failure. Parameters like rotor speeds, internal temperatures and internal pressures are used to gauge the total severity. Analysis has shown that these parameters are directly affected by two factors: stage length and the level of reduced thrust used. The takeoff phase places the most stress on an engine and is thus weighted more heavily; however, other factors emerge during cruise on longer flights.[3] Thus, although any carrier will benefit, short-haul airlines that put several cycles a day on their aircraft would gain the most from a reduced-thrust policy.

Considering the extreme operating conditions of a turbine engine's hot section, limiting wear should be an obvious goal. Turbine blade fatigue, in particular, is directly affected by high centrifugal forces and vibration stresses, and these loads have a direct relationship to increased turbine inlet temperatures. A study performed by the China Civil Aviation Flight College found a 51 percent reduction in blade life after 3,500 hours at 870 degrees C, compared to a 35 percent loss when operating at 705 degrees C, and a near doubling of hot section life overall.[4]

Tradeoff

Apart from safety, there is the consideration of noise reduction in our environmentally sensitive culture. It stands to reason that an engine operating at lower thrust will create less noise. As noted previously, reduced thrust, actual-condition takeoff distance is less than the assumed-condition distance. It is not, however, less than the takeoff distance at full-rated power. So, while "sideline" noise may be improved, the longer takeoff distance and lower climb path actually may put the airplane closer to noise monitors and increase "in-line" decibel levels.

Reduced thrust operations are always a tradeoff. How, then, should we define "safety" in these terms? Is it safer to use the maximum allowable power setting or to back off and reduce our exposure to failure during the most engine-critical phase of flight? Ultimately, it is up to the pilot to decide.

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Notes

1. Screen height is a parameter used in certification to determine an airplane's accelerate-go performance. Minimum screen heights, or heights above the departure threshold, are 15 ft for a wet runway and 35 ft for a dry runway.
2. Stopkotte, Jack. "Minimizing Costs While Maintaining Performance Margins, Part 1 — Lowering Costs and Improving Reliability." GE Aircraft Engines, September 2003.
3. Ibid.
4. Chenghong, Yan. "Reduced Thrust Takeoff." International Council of the Aeronautical Sciences Congress, 2002.