Flameout

Why the fire in a perfectly healthy jet engine can die.

By Peter Garrison

In the early afternoon of May 24, 1988, TACA Flight 110, a Salvadoran Boeing 737 arriving from Belize, was picking its way among thunderstorms ringing New Orleans when the unthinkable happened: Both of the airliner’s jet engines quit. Frantically, the crew members tried to restart them. At first they thought they had succeeded: Okay, one crew member radioed to controllers as the craft descended through 4,000 feet, we’ve got both engines back now. But relief evaporated less than a minute later. The engines would not accelerate from idle speed, and dangerously rising tailpipe temperatures forced the crew to shut them down again.

I don’t think that I will make it, I don’t have any power on the engines here sir, so I guess we having to go down, we have to go down, we declare emergency....

TACA 110, there is the interstate highway directly ahead of you....

I don’t believe we gonna be able to make it there sir, we’re at 2,000 and we’re losing altitude.... The only thing I do right now is make a 360 and I’ll land over the water sir.

TACA 110, I show your altitude now 700 feet.

Seven minutes later another airplane, at the request of the air traffic controller, flew over the area where the 737’s radar target had disappeared. The pilot caught sight of the airliner incongruously parked on the embankment of a levee beside Lake Borgne, its escape chutes deployed. With remarkable airmanship, Captain Carlos Dardano had dead-sticked the 737 onto a mile-long patch of rain-soaked earth. The airplane and its passengers were unharmed.

What happened to TACA 110 is called a flameout. The term is casually used for any failure in a turbine engine, but its technical meaning is more narrow: power loss not associated with a mechanical failure. A flameout of one kind or another is thought to occur once in every 100,000 non-military flights.

Three things are needed to keep a jet engine going: fuel, air, and the heat to make them burn. Removing any of the three can cause a flameout. In the case of TACA 110, what was taken away was the “activation energy”—the heat. The engines had been throttled back for descent, and their supply of internal heat was minimal; heavy rain and hail simply doused the fire. The event was not unique. Nine months earlier, an Air Europe 737 descending through rain and hail over Thessaloniki, Greece, had suffered a double flameout. In that case, the crew managed to restart the engines and land without trouble. In 2002, a Garuda Indonesia 737, also descending among thunderstorms, suffered a double flameout over Java. Its crew ditched the airplane in a river; one person died, and there were a dozen serious injuries.

Water and ice aren’t the only things that can turn off the fire in a jet engine. Unexpectedly, so can fuel. Obviously, running out of fuel is a good way to stop an engine, but too much fuel can have the same effect, if it comes from the wrong place.
Walt Larimer, a retired U.S. Air Force navigator, remembers an incident from the late 1950s in Morocco. An F-100 pilot, a novice at aerial refueling,

couldn’t get hooked up to Larimer’s KB-50J tanker. It took many attempts, but the pilot finally managed to engage the refueling drogue, only to fracture the coupling at the end of the fueling hose a moment later. Jet fuel began to stream out. The fighter, whose engine air intake is in its nose, dropped back and inadvertently slurped up some JP-4. A muffled explosion could be heard from inside the F-100, and flames emerged from its front and rear ends simultaneously. The fighter, its engine spooling down, dropped from sight while a fellow pilot who had been waiting for his turn at the hose shouted restart instructions.

Larimer later learned that the hapless pilot of the stricken jet failed to restart the engine. But he managed to glide back to his base and make a successful dead stick landing on the runway—a semi-miraculous accomplishment in an F-100.

Only a military pilot during a refueling operation is likely to encounter stray JP-4. For the rest of us, the atmosphere can contain even more insidious antagonists. Since 1980, the year Mount St. Helens in Washington state erupted, there have been at least 100 instances of airliners encountering clouds of volcanic ash, often hundreds of miles from the source; the clouds have done more than $250 million in damage to airplanes that unwittingly entered them. In two cases, passenger-carrying Boeing 747s have lost all power in all four engines. The first, a 1982 British Airways flight, glided from 37,000 to 14,000 feet in darkness over the south Pacific Ocean before its crew managed to restart the engines. The second, involving a KLM airplane in 1989, took place in Alaska; there too the pilots managed to restore partial power and land safely.

Volcanic ash, which is highly abrasive, sandblasts an airplane’s skin and windows, requiring extensive repairs. Inside the engines, its effects are more varied. Ash grinds away compressor blades and reshapes the airfoils of turbine blades and guide vanes by filling up their concave surfaces. It melts and fuses on the perforated walls of combustors. It plugs up the delicate shrouds and vanes of injectors, whose job is to vaporize the fuel and mix it with just the right amount of air to ensure ignition in the generally over-lean atmosphere of the combustor. All these effects are most disruptive at high altitude, where air is thin and the conditions of combustion are most critical; crews were able to get relights only after long and harrowing glides.

Like all internal combustion engines, a jet engine compresses air, then adds fuel and ignites it. The burning gases in the combustion chamber rush toward the open back end at high speed. On the way, they deliver power—in large engines tens of thousands of horsepower—to a turbine that drives the compressor at the front. The Newtonian equal-and-opposite reaction to gas shooting out the back is the force pushing the engine forward. The whole process sounds somewhat chancy, and is. Getting a jet engine to run, then keeping it running and under control, is not a simple matter. The early notebooks of Frank Whittle, the Englishman who invented the modern jet engine (independently of, but simultaneously with, a German, Hans Pabst von Ohain), are full of descriptions of dramatically brief tests, shrieking runaways, overheated burners, and melting turbine blades. Air, fuel, and engine speed must remain balanced within certain limits; otherwise, the fire either goes out or consumes the engine around it. The immensely reliable modern jet engine is the fruit of millions of hours and billions of dollars spent getting all the parts just right: the shapes of compressor and turbine blades and the stator blades that guide the flow between them, the lubrication and seals, and the geometry of fuel injectors and igniters. Besides perfecting these components, research has produced materials for the “hot section” in and downstream of the burners, where small parts made of exotic alloys with a melting point of 2,200 degrees Fahrenheit survive, thanks to elaborate and ingenious methods of insulating and cooling, in a steady bath of 3,000-degree

gas.
Nevertheless, seemingly small things can still make an engine quit. Very hot or disturbed intake air can do it. Adverse interactions between engines and armament have plagued many military jets. The engines of the A-10 “Warthog,” which are mounted on pylons beside the rear fuselage, suck up much of the gas that blows back from the muzzle of its 4,000-round-per-minute Gatling gun. Occasionally, as Air Force Captain Rusty Gideon learned the hard way (see “All Because of a Little Hot Air,” right), ingestion of gun gas can shut engines down.

The F-94 Starfire, a 1950s Lockheed fighter based on the F-80 Shooting Star, would sometimes flame out after firing salvos of rockets, which distorted the flow of air into its side-mounted engine air intakes. Even the relatively modern F-14 experienced interactions between its guns and its Pratt & Whitney TF-30 engines; its gun muzzles were retrofitted with special gas diffusers to alleviate the problem. Actually, the 21,000-pound-thrust TF-30 engine was notoriously prone to flameout for any number of reasons, including—rather inopportunely in the carrier-based Vought A-7, which had only one of them—the jolt of a catapult launch.

Improper inlet flow is said to be “distorted” because jet engines are happiest when the air entering the engine is going in the same direction, and at the same speed, at all points on the engine face. For the short inlets of airliner nacelles and the narrow range of flight attitudes they experience, uniform flow is easy to achieve. Fighters, however, present special challenges to designers. Their engines are normally buried within the fuselage and behind the cockpit, and air has to travel through ducts to reach them. Fighters maneuver violently. Inlets placed alongside the fuselage, like those of the F-14 and F-15, ingest distorted flow whenever the airplane’s nose swings to the right or left relative to the flight path. The F-16’s intake placement—like that of the Eurofighter, beneath the forward fuselage—tolerates maneuvering better.

Compressor stall—technically called surge—is a much more frequent phenomenon than flameout, and may lead to flameout. Surge occurs when engine speed, airflow, and fuel supply get out of balance and the required distribution of pressure throughout the engine is disturbed. Some or all of the blades in the compressor experience an aerodynamic stall, like that of the wing of an airplane when its nose is held too high. The abrupt pressure drop can generate one or more extremely loud bangs, and, in particularly dramatic cases, the flame from the combustor, no longer forced backward by incoming compressed air, can shoot out the front of the engine. Usually the engine recovers on its own. Frank Smith, a former Navy A-7 pilot, recalls a particularly startling compressor stall that happened during a practice dogfight in 1970. His opponent “went from 250 yards astern to 100 yards ahead in about one second while I experienced a complete end-swap and the biggest noise I ever heard from an aircraft that remained in one piece. But the engine kept running and rpm barely dropped before I was able to regain control. Hell, I really didn’t do anything but hang on.”

Surges do not always clear automatically; sometimes they are “locked in,” rotating in place within the compressor. Then, rising temperatures in the hot section force the pilot to shut the engine down. Loss of an engine affects other aircraft systems—hydraulic, pressurization, and electrical—all of which are supplied by engine-driven components. There are backup systems, but restarts can still be surprisingly difficult because of the distracting secondary effects of losing power.

Even within its operating envelope, however, the higher a jet flies, the narrower the “surge margins” that define how far conditions within the engine can stray from the optimum before it quits running. At sufficiently high altitudes, jet engines flame out simply because they run out of oxygen.

Not all flameouts are accompanied by noise or vibration or by any obvious triggering event. In some cases, especially on multi-engine airplanes, one engine may spool down unnoticed by the pilot, while autopilot and autothrottle conspire to mask the thrust asymmetry. In a few instances, crews have temporarily lost control because they failed to realize that one engine has stopped producing thrust.

A fatal accident in 2004 illustrates the potentially dire consequences of inattention to engine parameters and the unexpected difficulties that can beset restart attempts. Two pilots flying a Canadair regional jet to its next departure location decided, on a lark, to take the airplane up to its 41,000-foot ceiling, where neither had ever been. They programmed the autopilot to climb at a fixed rate. As the airplane ascended into ever thinner air and the engines produced less and less thrust, the autopilot had to keep reducing speed in order to maintain the commanded climb rate. The crew did not notice anything was wrong until both engines flamed out.

The pilots turned to the restart checklist, which first required descending rapidly to a lower altitude. Meanwhile the engines spooled down, and unequal cooling of closely fitting seals in the compressor caused them to bind—a condition now dubbed “core lock.” The engines would not spool up, either from windmilling or with the help of the auxiliary power unit. By the time the crew realized that the engines would not come back, they were too low to reach the nearest landing field. The aircraft crashed a couple of miles short of a runway; both pilots were killed.

Engines that have flamed out and that have not been damaged by, say, a violent compressor surge can, in principle at least, be restarted. The difficulty of restarting, and the time it takes, depend on several factors, one of which is how much the engine has spooled down. With sufficiently high forward speed and sufficiently low altitude—generally above 250 knots and below 25,000 feet—engines can windmill up to a speed sufficient to permit ignition; then they gradually bootstrap back to operating speed and compression. Although jets, like any airplane, can glide without power—airliners can progress 10 miles or more horizontally for every mile of altitude they give up—the speed required for a windmilling start is much higher than the best glide speed, and so altitude melts away rapidly during restart efforts.

Military jets are regularly tested for restart ability—for example, after an engine upgrade or modification. In twin-engine airplanes it’s routine work, but when an airplane has only one engine to begin with, it can occasionally get tense. Art Nalls, now retired from the Marine Corps, recalls a wintertime test of a TA-4J—a training version of the single-engine A-4 Skyhawk—at Edwards Air Force Base in California. The giant lake bed, an alternate landing site for space shuttles, is normally bone dry, but recent rains had soaked the ground and left it largely flooded.

The test card called for restarts at selected points along the edge of the restart envelope; if the engine failed to relight, Nalls would move to the “heart of the envelope,” where the engine was considered sure to start. “One of the last points was a low-altitude, slow-airspeed point that left little margin for error,” he remembers. “Only a small portion of the lake bed was available for landing, and it was soft. Quite possibly the airplane could flip over. But it was legally usable and met the criteria of our test plan, so we elected to continue. We were almost done with the project, everything had worked normally so far, and get-home-itis had started to set in.”

Already at a low altitude when the test began, Nalls found it impossible to restart the engine. Only when he was below 1,000 feet, seconds away from a landing on the muddy lake bed, did the engine finally relight. It later turned out that the cause of the trouble had been a malfunctioning ram air turbine—the backup electrical source for the engine’s igniters.

Nalls was a test pilot, and test pilots feel strong pressure to bring back the ship in one piece. Under the same circumstances, a service pilot whose jet had flamed out would long since have ejected. The likelihood of making a successful dead stick landing in a jet fighter is considered so slight that the military services have wavered on whether “flameout approaches” should be taught at all.

Though the reliability of jet engines is far better than that of the reciprocating engines that they largely replaced half a century ago, the danger of flameouts hasn’t disappeared. Flameouts are a natural consequence of the way jet engines work. They live on an island of stable operation—a dynamic balance of powerful forces—ringed by a sea of instability.

http://www.airspacemag.com/issues/2006/august-september/flameout.htm