Flight Data Recorders
Built to Survive

BY TONY BAILEY

OK, I know the truth. Most avionics technicians will never get involved with the internal workings of a flight data recorder (FDR) and if they do, it is probably because they work for one of the original equipment manufacturers (OEM) like Boeing, Cessna or Gulfstream. So, why is the FDR the most recognized piece of aviation electronics? The FDR, or better known as the "Black Box," is a common household term because of the dynamic function it performs and the amount of media attention it receives after a catastrophic aircraft failure.

Usually, a statement like this makes headlines just after a catastrophic flight occurrence:

"Data from two voice recorders from Air France Flight 358 has been successfully downloaded, the lead investigator into the accident said Friday. The black boxes, containing the flight data and cockpit voice recorders, had been quite damaged in the fire and investigators were concerned whether they would be able to retrieve information. 'So I think that's a good surprise and certainly I'm very relieved to find out that data was good quality data,' Transportation Safety Board investigator Réal Levasseur told reporters."

Although FDRs are called "black boxes," aviation recorders are actually painted bright orange. These distinct colors, along with the strips of reflective tape attached to the recorder's exterior, help investigators locate the black

boxes following an accident. These are especially helpful when a plane lands in the water. There are two possible origins of the term "black box." Some believe it is because early recorders were painted black, while others think it refers to the charring that occurs in post-accident fires.

Of course, the adoption of FDRs was not without trials and tribulations. Efforts to require crash-protected flight recorders date back to the 1940s. The introduction of FDR systems, however, experienced many delays. That's because technology could not match the design requirements of a unit that could survive the forces of an aircraft crash and the resulting fire exposure until 1958, when the world authorities approved minimum operating requirements for an FDR. This was about the beginning of the so-called "Jet Age," with the introduction of such aircraft as the Boeing 707, Douglas DC-8 and the Caravelle.

The initial requirement of these newly mandated data recorders was to record the actual flight conditions of the aircraft, i.e., heading, altitude, airspeed, vertical acceleration and time. These early devices had very limited recording capabilities. The five analog parameters of heading, altitude, airspeed, vertical accelerations and time were embossed onto a metal foil (Incanol Steel), which was used only once. The foil was believed to be nearly indestructible; however, crash survival remained a serious problem. Original requirements were for a unit to be able to withstand a 100 G impact and be installed in the forward avionics bay with the rest of the avionics boxes. After several accidents with aircraft equipped with FDRs, it soon became evident that the 100 G specification was inadequate. To correct the situation, the Federal Aviation Administration (FAA) in 1965 made a specification change which increased the impact requirements to 1,000 Gs and relocated the recorder to the rear of the aircraft. The reasoning for the change was that, following initial impact, the rear of the aircraft would be moving at a slower speed, thus, more recorders would survive.

With just five parameters, however, there was not enough recorded data for a meaningful accident investigation. Consequently, in 1987, these recorders became unacceptable to most government regulatory authorities and additional parameters were required. Although most major airlines replaced these old-technology recorders long before required by law, many of these first-generation recorders are still flying in older model aircraft. The remainder of these foil recorders will soon be unusable, since the industry supply of the lncanol Steel recording medium has been depleted.

However, flight data containing five parameters alone could not provide all the accident information needed by the investigators. A new "tape" technology (recording data in a digital format) was expanded to the FDR. This second-generation FDR allowed a manufacturer to build products that would record many additional flight parameters while meeting higher crash and fire protection requirements. In the late 1960s and early 1970s, the introduction of sophisticated aircraft such as the B-747, DC-10, L-1011 and A300 required new recorders that could retain information about the engines, flight controls, flaps, etc., that fully assist accident investigators.

In the late 1960s, England's Civil Aviation Authority required that additional parameters be recorded. Several versions of FDRs were available with multiple metal styli that allowed marking on both sides of the foil. This allowed for the recording of pitch, roll and flaps. While this provided additional information for the accident investigator, it generated much more work for the shops and resulted in lower reliability of the unit. Moreover, this additional information was very difficult to read and even harder to interpret. By installing a Flight Data Acquisition Unit (FDAU), these analog aircraft could provide much more data. The new specification required a new digital type recorder that would record 64 12-bit words each second for 25 hours, which represented the round-trip time between New York City and Japan or between Los Angeles and Europe.

The FDAU would take in all of the analog signals, convert them, and then send a single digital data stream to the crash-protected "tape" unit. In the late 1970s and early 1980s the International Civil Aviation Organization (ICAO) began recommending that digital aircraft record 32 parameters. As the ICAO had no enforcement capabilities, each country continued to follow its own existing regulations; however, their goals were to eventually meet the ICAO recommendations.

In the United States, the FAA requires that commercial airlines record a minimum of 11 to 29 parameters, depending on the size of the aircraft. Magnetic-tape recorders have the potential to record up to 100 parameters.

The Solid State Flight Data Recorder (SSFDR) became commercially practical in 1990. "Solid State" refers to storage of data in semiconductor memories or integrated circuits, rather than using the older technology of electromechanical methods of data retention. SSFDRs can record more than 700 parameters or seven times the capability of magnetic-tape recorders. On July 17, 1997, the FAA issued a Code of Federal Regulations that requires the recording of at least 88 parameters on aircraft manufactured after Aug. 19, 2002.

Since the solid state memory does not require scheduled maintenance or overhaul, there are potential cost savings to the operator. Additionally, the data is easier to retrieve, and is readily available to assist in monitoring the performance of the aircraft, or during scheduled maintenance inspections. Using technology of the third-generation recorders, operators can extract stored data in a matter of minutes. This data can show how the aircraft has performed in flight, or if a monitored device needs maintenance. Now, the operators of newer generation aircraft can fly with greater safety and reliability.

Of course, the data is only good if it is protected. The search for this seemingly indestructible box amidst the debris of the wreckage is akin to the quest for the Holy Grail. But in the absence of any survivors or eyewitnesses, it is within these steel walls of the box that the digital recordings of the last few minutes of flight are stored, thus the best prospect for clues to the disaster. But there is no guarantee that even if found, the FDR will have the answers.

So, after many years of operation, the FAA increased the durability requirements on the recorders and their casings to survive severe impact and fire. All aircraft capable of carrying 10 or more passengers for scheduled commercial use are required to have voice and data recorders connected to the electrical power generators of the aircraft's main engines.

The storage medium of each recorder is located in a protective capsule, which must be able to withstand an impact of 3,400 Gs (3,400 times the force

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Terms and Definitions

CSMU	Crash Survivable Memory Units
FDAU	Data Acquisition Unit
ECAM	Electronic Centralized Aircraft Monitor
EFIS	Electronic Flight Instrument System
FAA	Federal Aviation Administration
FDAU	Flight Data Acquisition Unit
FDR	Flight Data Recorder
HSI	Horizontal Situation Indicator
ICAO	International Civil Aviation Organization
OEM	Original Equipment Manufacturers
PFD	Primary Flight Display
PSI	Pounds per Square-inch
SSFDR	Solid State Flight Data Recorder
ULB	Underwater Locator Beacon

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The damaged flight data recorder from EgyptAir Flight 990.

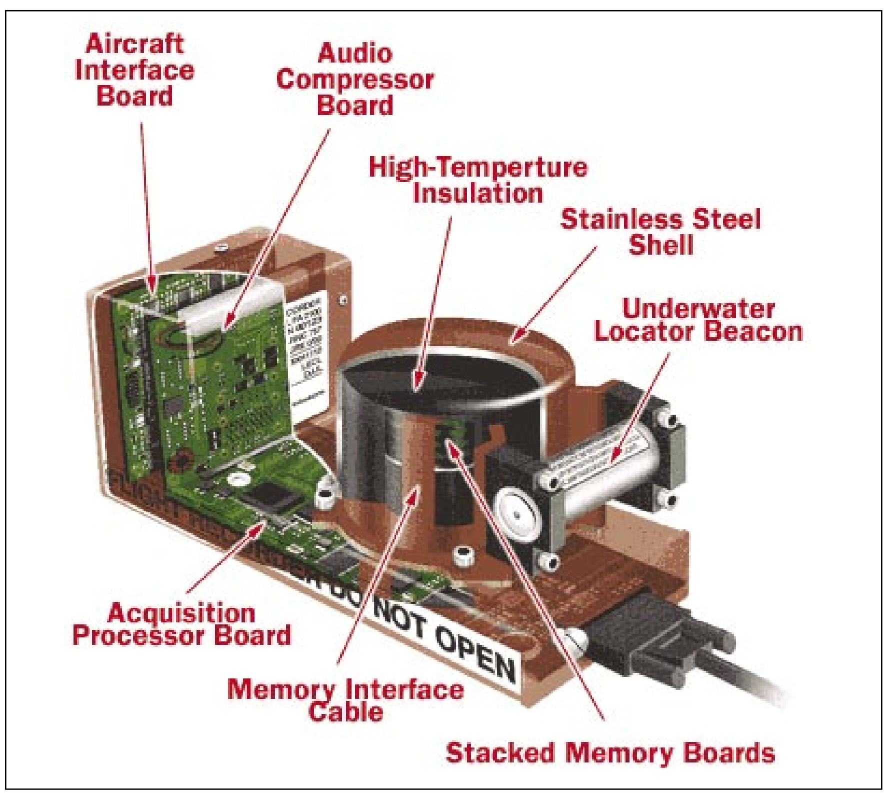
of gravity). Additionally, each must also survive flames at 2,000 degrees Fahrenheit for up to 30 minutes, and submersion in 20,000 feet of saltwater for 30 days. Most flight data recorders are constructed with an aluminum sheet metal chassis, with a protective capsule constructed of heat-treated stainless steel or titanium. Because new solid-state digital recorders have no moving parts and are smaller than their predecessors, they are lighter than analog tape devices, and use less power. In many accidents, the only devices that survive are the Crash Survivable Memory Units (CSMU) of the flight data recorders and cockpit voice recorders. Typically, the rest of the recorders' chassis and inner components are mangled. The CSMU is a large cylinder that bolts onto the flat portion of the recorder. This device is engineered to withstand extreme heat, violent crashes and tons of pressure. In older magnetic-tape recorders, the CSMU is inside a rectangular box.

To ensure the quality and survivability of black boxes, manufacturers thoroughly test the CSMUs. Remember, only the CSMU has to survive a crash—if accident investigators have that, they can retrieve the information they need.

There are several tests that make up the crash-survival sequence:

- **Crash impact**—Researchers shoot the CSMU through an air cannon to create an impact of 3,400 Gs. At 3,400 Gs, the CSMU hits an aluminum, honeycomb target at a force equal to 3,400 times its weight. This impact force is equal to or in excess of what a recorder might experience in an actual crash.
- **Pin drop**—To test the unit's penetration resistance, researchers drop a 500 pound (227 kg) weight with a 0.25 inch steel pin protruding from the bottom onto the CSMU from a height of 10 feet (3 m). This pin, with 500 pounds behind it, impacts the CSMU cylinder's most vulnerable axis.
- **Static crush**—For five minutes, researchers apply 5,000 pounds per square-inch (psi) of crush force to each of the unit's six major axis points.
- **Fire test**—Researchers place the unit into a propane-source fireball, cooking it using three burners. The unit sits inside the fire at 2,000 degrees Fahrenheit (1,100 C) for one hour. The FAA requires that all solid-state recorders be able to survive at least one hour at this temperature. During the fire test, the memory interface cable that attaches the memory boards to the circuit board is burned away. After the unit cools down, researchers take it apart and pull the memory module out. They re-stack the memory boards, install a new memory interface cable and attach the unit to a readout system to verify that all of the preloaded data is accounted for.
- **Deep-sea submersion**—The CSMU is placed into a pressurized tank of salt water for 24 hours.
- **Salt-water submersion**—The CSMU must survive in a salt water tank for 30 days.
- **Fluid immersion**— Various CSMU components are placed into a variety of aviation fluids, including jet fuel, lubricants and fire-extinguisher chemicals.

While recorders are placed in the tail of an aircraft to increase survivability, the distance from the parameters recorded requires long cables running the length of the plane. If the plane be-



Internal Design of a Typical FDR

gins to break up or power is otherwise severed prior to a crash, recorded data can be lost.

In March 1999, the NTSB made several recommendations to the FAA concerning black boxes. The board suggested that the FAA require a retrofit program after Jan. 1, 2005. In this retrofit, all aircraft carrying analog tape recorders would be furnished with solid-state digital units, which also would feature an independent power source able to support 10 minutes of operating time and engage automatically when aircraft power ceases. To improve data retrieval, the NTSB has also recommended that all aircraft built after Jan. 1, 2003, be equipped with two combination voice and data recording systems. Both systems should continue to record all mandatory parameters, but one set should be located close to the cockpit and feature an independent power supply, while the other should be mounted in the tail section.

Redundancy, independent power sources, and longer voice recordings are big steps in making sure data is reliable, detailed, and clear which is a key factor in accident investigations.

What people often don't know is that in addition to the paint and reflective tape, FDRs are equipped with an Underwater Locator Beacon (ULB). If you look at a picture of an FDR, you will almost always see a small, cylindrical object attached to one end of the device. While it doubles as a handle for carrying the black box, this cylinder is actually a beacon to help locate the box after a water crash. If a plane crashes into the water, this beacon sends out an ultrasonic pulse that cannot be heard by human ears but is readily detectable by sonar and acoustical locating equipment. There is a submergence sensor on the side of the beacon that looks like a bull's-eye. When water touches this sensor, it activates the beacon.

The beacon sends out pulses at 37.5 kilohertz (kHz) and can transmit sound as deep as 14,000 feet (4,267 m). Once the beacon begins "pinging," it pings once per second for 30 days. This beacon is powered by a battery that has a shelf life of six years. In rare instances, the beacon may get snapped off during a high-impact collision.

Once the design stability of FDRs had been satisfactorily achieved, the next step was the integration of three-dimensional animation technology for accident investigation purposes. With the data retrieved from the FDR, the Safety Board can generate a computer animated video reconstruction of the flight. The investigator can then visualize the airplane's attitude, instrument readings, power settings and other characteristics of the flight. This animation enables the investigating team to visualize the last moments of the flight before the accident.

Aircraft animations with synchronized cockpit instrumentation are an effective means of presenting results, and drawing cause-effect relationships from recorded flight data.

The animation of an event encompasses the aircraft's flight profile, cockpit instrumentation, terrain and scenario data. With an ever increasing number of parameters being recorded on aircraft, a method of relaying the large amounts of available information in a meaningful manner is needed. 3D animations are one such method to effectively recreate flight information to determine what the aircraft was doing at any given moment.

Flight reconstruction consists of utilizing recorded flight data to derive the aircraft's instantaneous position and orientation relative to an orthogonal, right-handed Cartesian frame of reference that is fixed to the Earth. Several algorithms exist for calculating an aircraft's flight path, which require different sets of input parameters. The total set of parameters includes airspeed, pressure altitude, radio altitude, ground speed, drift angle, roll attitude, pitch attitude, heading (true or magnetic), glideslope deviation, localizer deviation, magnetic variation, wind speed, wind direction, temperature and station pressure.

Aircraft animation snapshot with instrument panel and terrain elevation data.

Technology has made these animation programs incredibly accurate and detailed. The graphical display of data-driven instrumentation is a means of relaying the recorded flight data in a manner similar to what the pilot may have observed in the cockpit. Some examples of cockpit instrumentation include: control stick, control wheel, tachometer, altimeter, horizontal situation indicator (HSI), airspeed indicator, electronic flight instrument system (EFIS), primary flight display (PFD) and electronic centralized aircraft Monitor (ECAM).

While FDRs are successful in aircraft, new demands and needs have spread out into the non-aviation world. Black boxes aren't just taking flight—they're being grounded as well. Several automobile manufacturers are utilizing black box technology in their

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Glideslope animation based on FDR data.

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automobiles and a few have been doing so for quite some time. According to an article titled "Black boxes in GM cars increasingly help police after accidents," General Motors has been using black box technology for over a decade. The manufacturer has been installing a Sensing and Diagnostic Module on thousands of its cars, including the Corvette. Furthermore, this article reports that "industry insiders say as many as a dozen other manufacturers install similar technology under different labels."

So, black box technology has moved from airplanes to automobiles—where is it headed next? It could be on you. Right now it's just a prototype, but soon the SenseCam could provide you with an incredible amount of information about—well, you!

Let's say you attended the recent AEA convention. Because you forgot your PDA, you were forced to scribble dozens of phone numbers and emails down on random business cards, napkins, and note pads. You made plans with several colleagues, but much like the random napkins in the washing machine at home, your memory just didn't hold up. But, all would not be lost—if you were wearing a SenseCam. According to its manufacturer, this badge-sized wearable camera reportedly captures up to 2000 VGA images within a 12-hour day and stores it in a 128Mbyte flash memory. So, most every scribbled note and every promised meeting would be recorded for you to look at later.

So there you have it. The device that not only survives crashes, but time as well. ❑