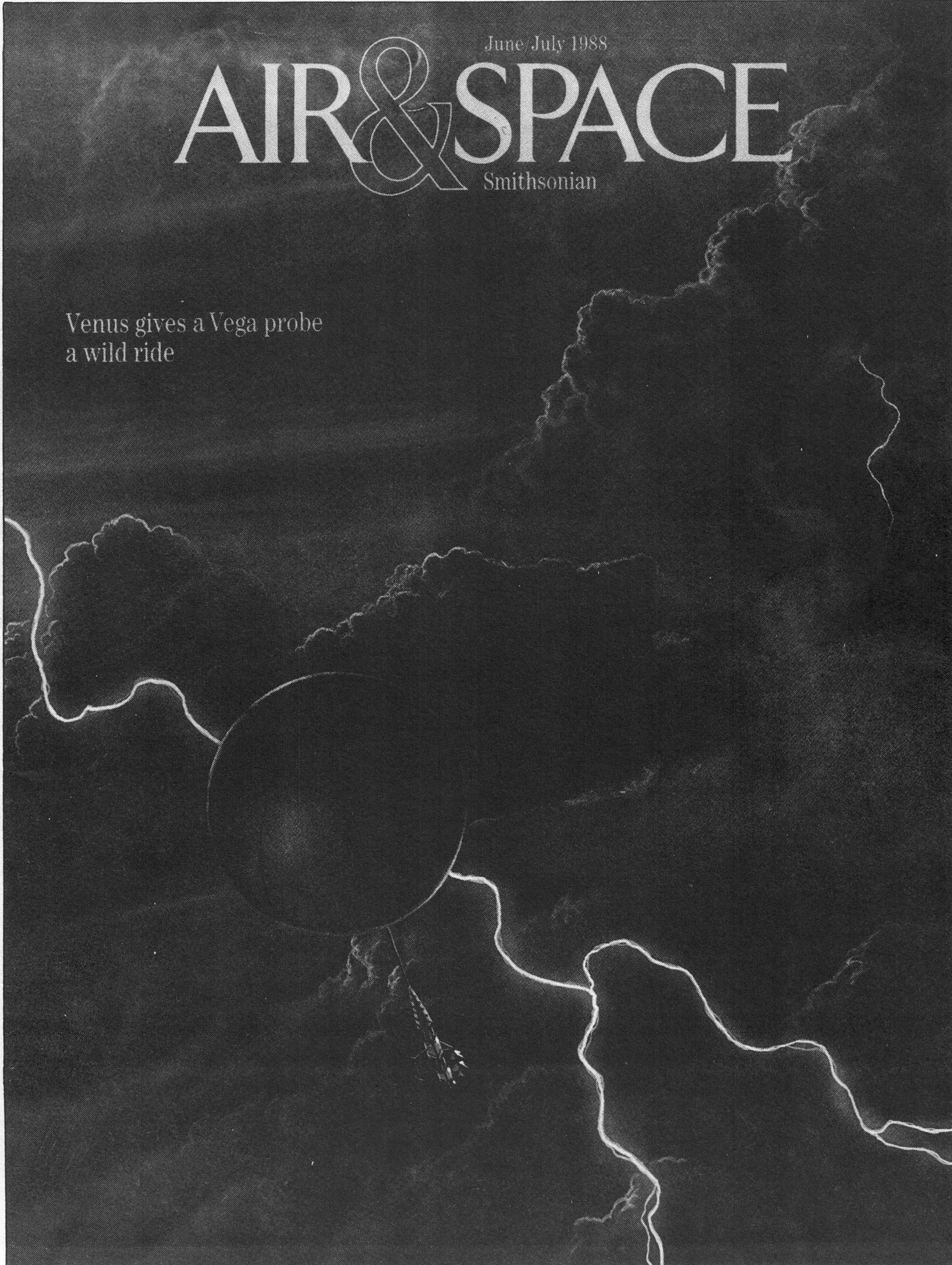
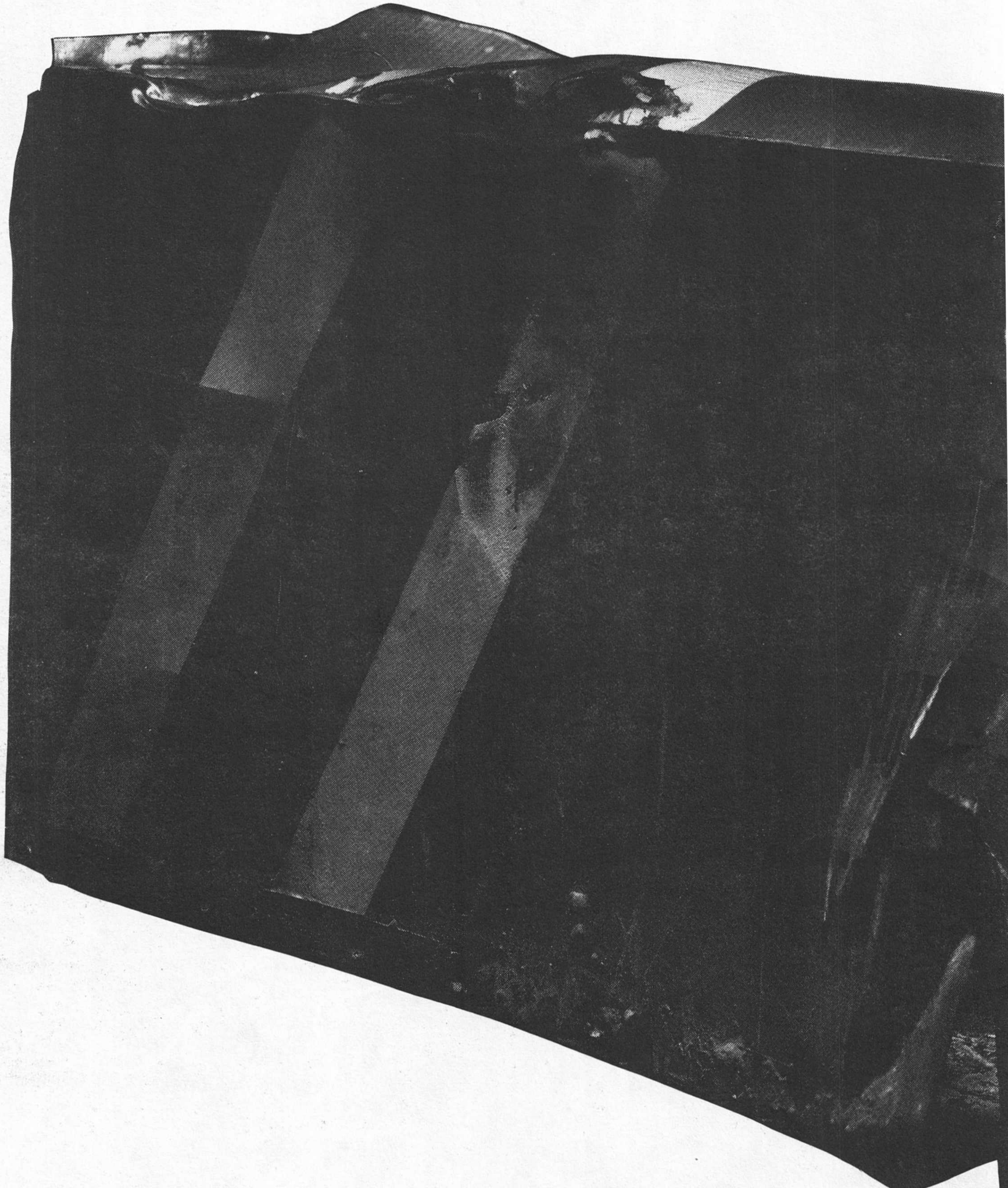
June/July 1988

AIR&SPACE

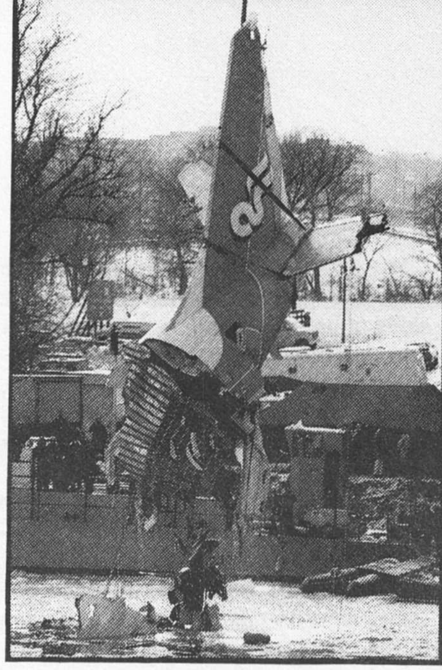
Smithsonian

Venus gives a Vega probe
a wild ride





"THIS ARTICLE APPEARED IN THE JUNE/JULY, 1988 ISSUE OF AIR & SPACE AND PERMISSION TO REPRODUCE ITS' CONTENTS WAS GIVEN BY THE PUBLISHER."



Benn/Coulson/Woodfin Camp, Inc.

THE BLACK BOX

When airplanes crash, flight recorders often tell why.

by Patrick Cooke

Many people would consider Jim Cash's job unbearably grim. As part of the National Transportation Safety Board's team of accident investigators, Cash listens to tapes from cockpit voice recorders pulled from the wreckage of crashed airplanes.

Cash and his colleagues at the NTSB listen to the language of flight recorders, the "black boxes"

A cockpit voice recorder, like the one recovered from a crash in Virginia (left), told the story of Air Florida flight 90's last moments.

Breton Littlehales

that expose the causes of many airplane accidents. It is a job that demands the skills of both engineer and detective. It also requires a certain amount of emotional detachment: at one point in 1985, black boxes entered the investigators' windowless offices at a rate of several a month.

Cash was only two days on the job when he got his first tape. A United DC-8 cargo airplane had crashed in Detroit in 1983 shortly after takeoff, killing the three crew members aboard. Listening to the tape, Cash realized that the captain had allowed the flight engineer, who was not qualified to fly the airplane, to switch seats with the first officer and handle the takeoff. Because he had made his preflight check in a cursory way, the engineer didn't notice that the airplane's trim tab was still set to keep the nose up for a softer landing. When the flight engineer lifted the improperly trimmed airplane off the ground it rose nose-high, stalled, and crashed.

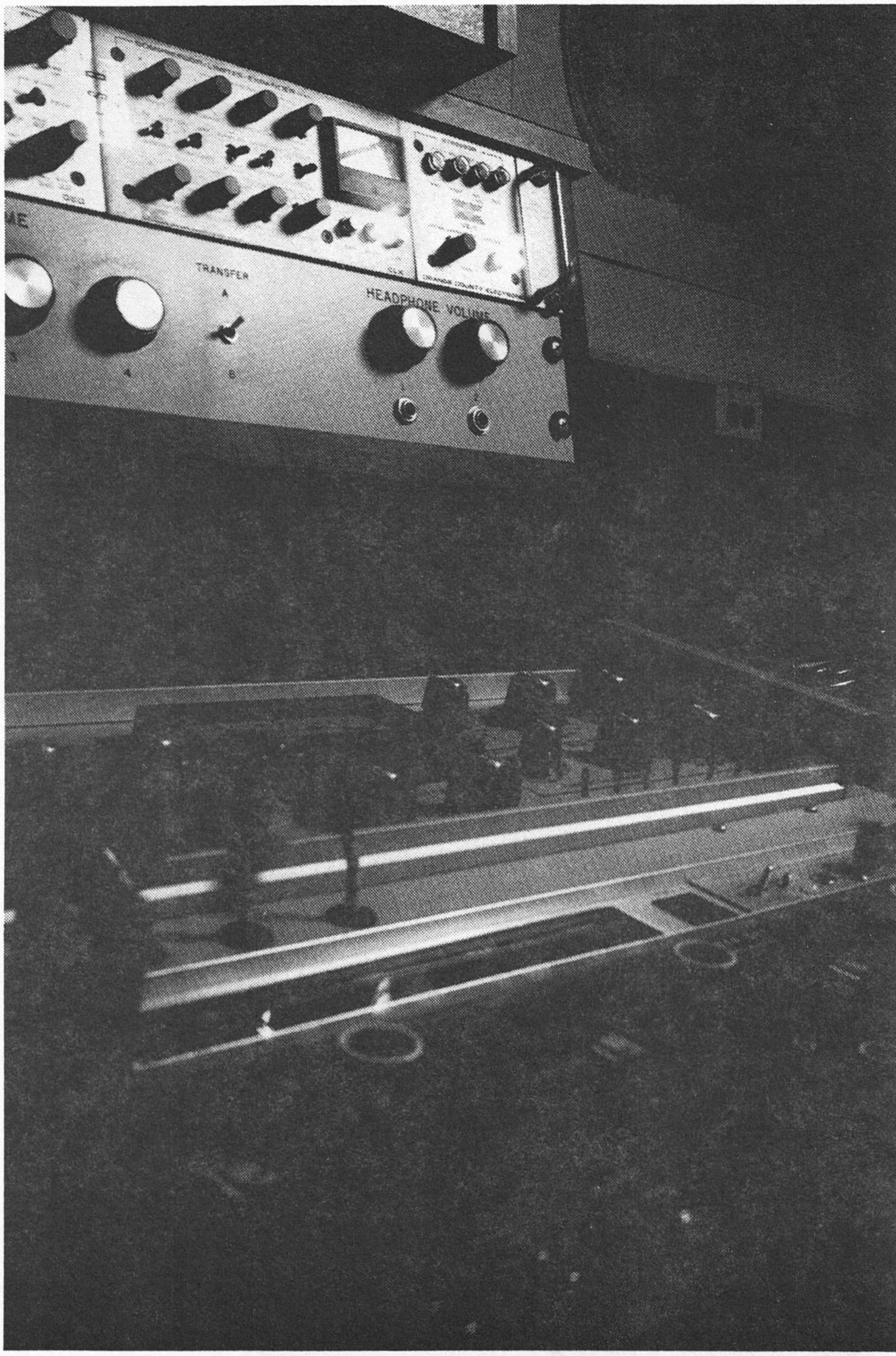
Five years later Cash still remembers listening to that tape. "The first few get to you," he says. But now, listening to the taped evidence of disaster is just part of a day's work.

The most distinctive feature of a standard black box is that it is bright orange or sometimes yellow, not black. Officials at the NTSB aren't even certain how the misnomer arose, but in any case the bright color makes the boxes easier to spot in wreckage. The other notable characteristic is that large airliners carry not one black box but two. Cockpit voice recorders pick up conversations and noises inside the cockpit; data recorders record different parameters of the airplane's performance.

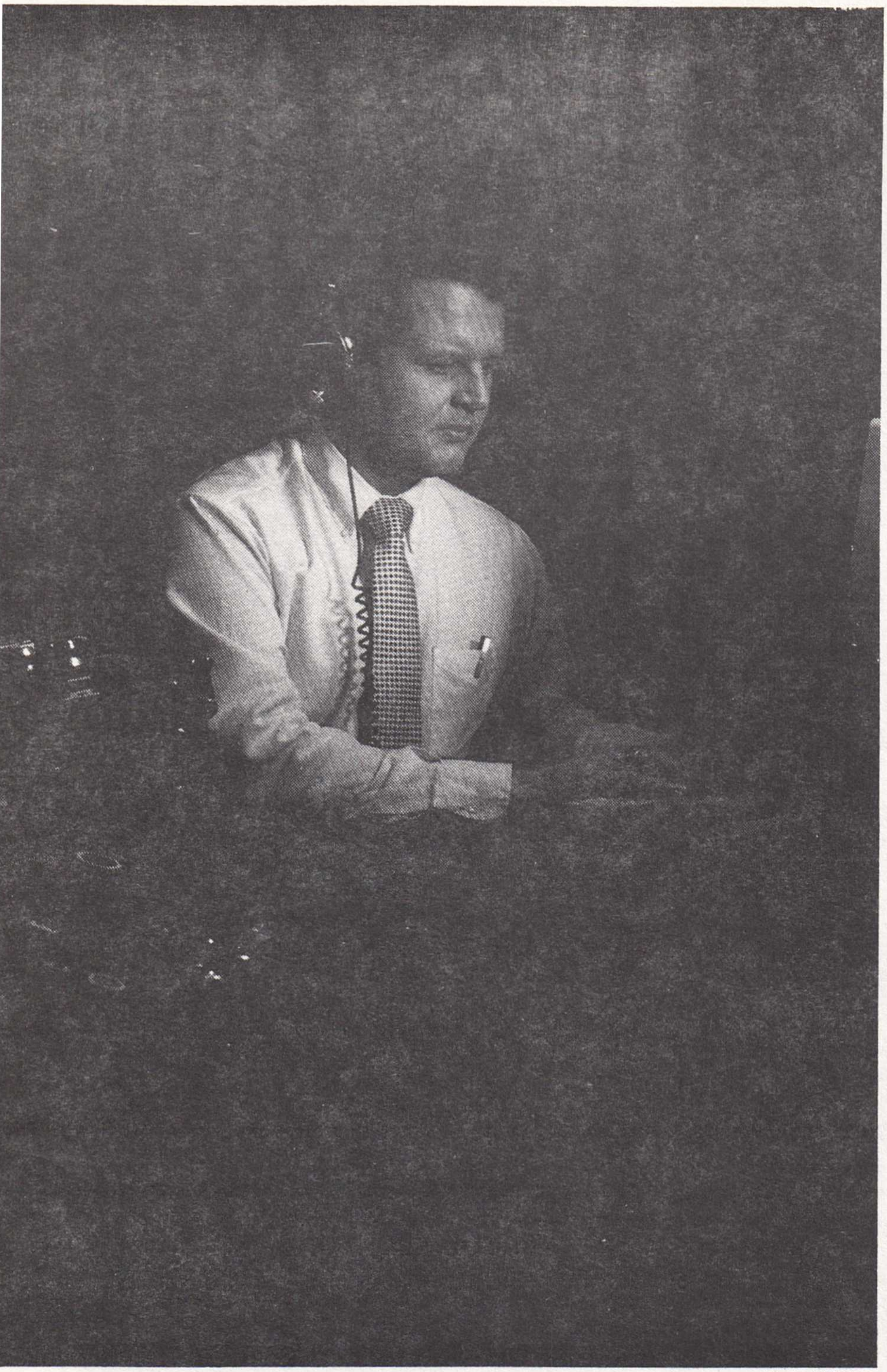
The boxes help link together the complicated clues of accident information—control tower radio traffic, weather information, wreckage inspection (see "The Go Team," August/September 1987). Flight recorders alone can't always provide the answers. "It's one thing to be able to read information that comes in," says NTSB engineer Dennis Grossi, "but it's quite another to be able to tell from it what might have happened to a plane." Still, the boxes often send accident investigators in the right direction.

A direction was about all Paul Turner, an investigator who retired from the NTSB last year, had before the black box eventually told him what happened to Air Florida's flight 90 on January 13, 1982. The airplane had crashed into the Potomac River shortly after taking off from Washington's National Airport. A blizzard had passed over Washington that day, and other pilots had seen ice forming on the airplane's wings during the long wait to take off in the storm. The natural assumption was that the ice had led to the crash—but the black box told more.

At some point before takeoff, ice had blocked an outside engine sensor, creat-



At the NTSB offices in Washington, Jim Cash begins his accident investigation by transcribing the tape from a cockpit voice recorder.



Breton Littlehales

ing a false power reading on the gauges in the cockpit. Something's "not right," the copilot said as the airplane rolled down the runway during takeoff. Turner heard the words later on the tape from the voice recorder, but he heard something else as well. He compared the sound frequency of the airplane's engines with normal takeoff frequency and realized the pilot had placed all his faith in the gauges. He simply never gave the ice- and snow-laden airplane enough throttle to climb. By the time the pilot did push the power up, says Turner, it was "too little, too late."

The evidence from the black box made it unlikely that another airplane will be lost for just that reason. But the problem, as it always has been, is that no two crashes are exactly alike.

The black box has changed considerably since the day Charles Lindbergh's *Spirit of St. Louis* carried a primitive version on its transatlantic crossing. (It recorded the altitude and time data needed to verify his flight.) For years afterward, data recorders—sometimes carried on the radio rack or tucked inside the airplane's wheel well—were strictly optional equipment. In 1947 the Civil Aeronautics Board made their use mandatory, but the devices proved so unreliable that the board rescinded the requirement the next year. A decade later the state of the art had developed to the point that the board began requiring flight data recorders on large carriers and commercial airplanes. Cockpit voice recorders became required equipment in 1967.

This year flight recorders on U.S. aircraft are in the middle of a revolution. After years of recommendations by the NTSB (which isn't a rule-making agency), the FAA has proposed new rules making the boxes mandatory on the smaller airplanes of the rapidly expanding commuter fleet. Many recorders already on board larger airliners are due to be replaced by more advanced models. In addition, the FAA is requiring that the boxes collect more kinds of information. "It's a big jump forward," says Grossi. "Of all the major countries, the U.S. had the worst regulations. Now we have the best."

A new flight recorder can cost from $9,000 to $20,000, depending on sophistication, but reliability is improving, and survivability in a crash is all but perfected. Each recording device is enclosed inside a protective casing that rivals an armored truck for security. First it is packed inside tough plastic water-filled bladders, or "shock mounts," which will protect the recorder from impact and shield it for at least 30 minutes from a fire as hot as 21,000 degrees Fahrenheit. A three-eighths-inch-thick stainless steel crash jacket is bolted around the unit, with another layer of stainless steel forming the outer skin. Attached to the outside is an underwater locating beacon that is activated by contact with water and will sound for 30 days with a decent battery. The complete package weighs about 25 pounds and is roughly the size of a small toolbox.

Black boxes are routinely tortured at Fairchild Weston Systems, Inc., one of the handful of manufacturers. In one test a 500-pound weight with a quarter-inch-long protruding pin is dropped on the box from a height of 10 feet. The pin must not damage anything inside the box. Boxes are also baked to thousands of degrees and must survive an impact of 1,000 Gs for five milliseconds, roughly comparable to a jet at full speed instantly dissipating all its energy into a mountain. Because some crashes consist of multiple impacts, impact forces up to six times that strong have been recorded, but the black box usually survives because it is located as far back in the aircraft as possible—normally the last part of the airplane to hit.

There is only one basic kind of voice recorder used in the United States, but until next year data recorders will come in two forms: scratch type, the first generation of recorders, which airlines began installing after 1958, and the more advanced digital recorder. Grossi sees both kinds come through his NTSB lab in Washington, a bright, noisy room overrun with banks of computer equipment. He is anything but undecided about which he prefers. "The scratch-type data recorder is so sloppy that the information that comes out of it is often just lousy," he says.

Inside a scratch recorder, data is recorded on a roll of light stainless steel or aluminum foil, slightly thinner than common kitchen foil, that travels over a set of rollers at a rate of 1/10 of an inch per minute. Each second, five needles—similar to those on lie detectors—strike the foil, creating scratches indicating changes in altitude, airspeed, vertical acceleration, and heading. The fifth parameter synchronizes timing of the data and voice recorders so that conversations coincide with events when both are played back.

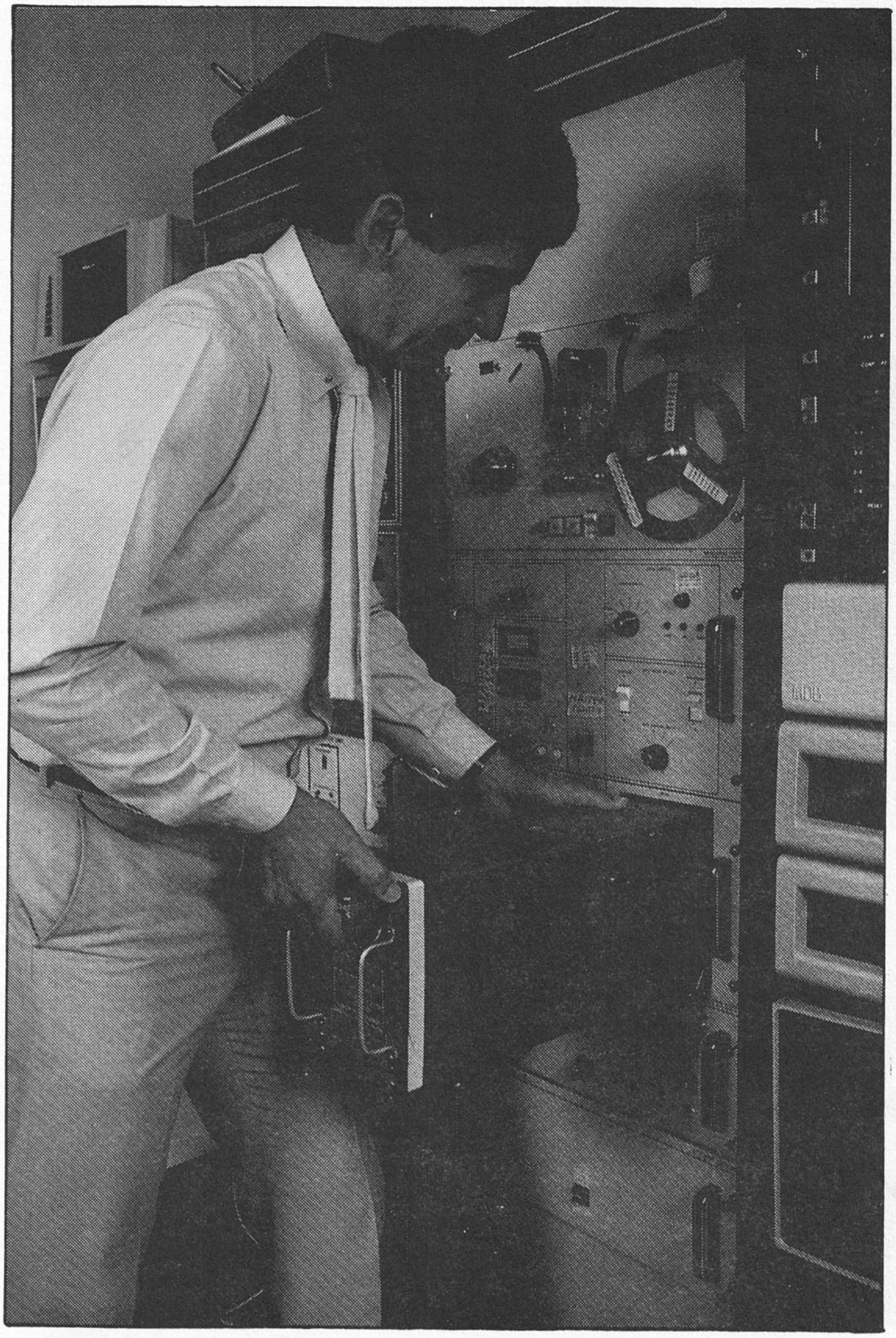
Should an airplane be involved in an incident, investigators send the foil to the NTSB. There, Grossi's technicians unroll it under an optic reader, a kind of microscope, and begin the painstaking task of examining the scratches. Ideally, the trail of marks should give a second-by-second reading of the changes the airplane went through up to the time of the incident.

But it doesn't always work that way. Take the case of a 1982 wind shear accident in New Orleans that downed a 727 carrying a scratch recorder.

"These are blowups of the foil from that crash," says Grossi, holding up a large photograph that looks more like an underwater picture of stones scattered across the ocean floor. "You can see from these tiny scratches where he started to get in trouble." He draws a line through the stones. "Here's where he probably hit the trees. But it's hard to determine from point to point exactly what the progression of marks is. The needles are just too inexact, and if one data point is wrong it throws the whole reading off. So there's an enormous amount of interpretation that goes into trying to piece together what actually happened. Much of it didn't even jibe with the physical evidence that later turned up."

The information from that accident was so unreliable, says Grossi, that in-

David Hathcox



Sometimes a flight data recorder survives an accident in reasonably good shape, making it easier for Dennis Grossi to retrieve its information.

By pairing a data recorder with computer graphics, investigators can simulate the events leading up to an accident.

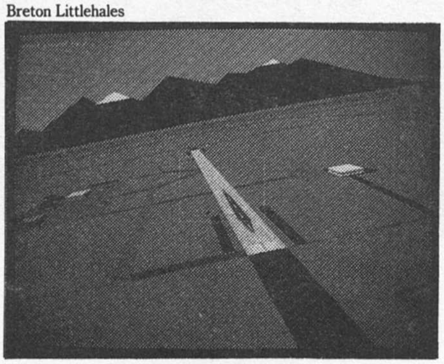
vestigators did not even bother trying to duplicate the crash on a simulator, a device that allows a flight to be "flown" via computer graphics using black box information.

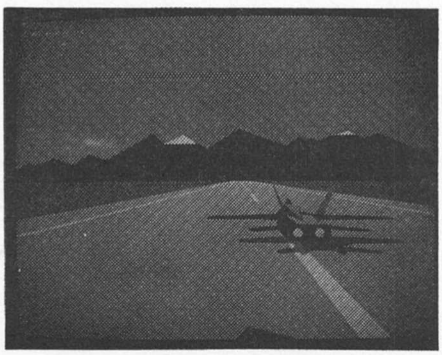
Much to the NTSB's relief, scratch recorders will become museum pieces by next May, thanks to recent regulations requiring that they be replaced by the more reliable digital recorders. Although they fit into the same containers as the scratch type, the digital recorders are a technological leap ahead of their predecessors. Instead of recording on foil, digital boxes log information on reusable, multi-track half-inch magnetic tape, similar to the tape used for music cassettes except that it can survive up to a year in sea water.

With a digital system, information is plucked from cockpit instrumentation or from sensors placed around the airplane and collected by a small control center called a data acquisition unit. The unit, which is usually not in the black box, converts the data into digitally coded signals, then sends the signals back to be stored on tape.

When a digital tape arrives at the NTSB, a computer decodes the binary data onto yards of printed paper. This numerical readout shows the crucial short-term changes in an airplane's final moments before a mishap.

Breton Littlehales





Aside from the obvious advantage of fewer moving parts, the digital system can record many more parameters than the scratch recorder's five. Most digital boxes record a standard 17 parameters: the five parameters of the scratch recorders, plus radio data, airplane attitude and acceleration, control status, engine thrust, and flap positions. The boxes have the potential to log more than 110 parameters, everything from brake pressure and fuel flows to the position of various switches and the readings of gauges in the cockpit.

Three years after the New Orleans accident, a Lockheed L-1011 crashed in Dallas, also a victim of wind shear. But this time the airplane had a digital recorder. "We learned so much about wind shear from the Dallas crash simply because we could actually document in detail the forces that acted on the plane in the last few seconds," says Grossi. "Probably the greatest advantage of the system is that the more parameters you have, the easier it is to weigh one against the other. If you have a suspect reading you can always go to another place and check it."

No one suggests that the New Orleans crash could have prevented the Dallas tragedy. But investigators do say that accurate information from the New Orleans accident would have at least permitted an additional simulator flight to be made through wind shear conditions, adding to the knowledge about this hazard.

Digital recorders were slow to appear in the U.S. airline fleet. In 1969 the FAA required that airliners carry digital recorders measuring a minimum of 17 parameters, but only airplane models certified after that year were affected. The Boeing 737, for example, was certified in 1966, so 737s were not required to record any more than the basic five parameters using either system.

The reason for limiting the modernization requirements was cost: rewiring a fleet of airplanes and retraining mechanics is costly and time-consuming. "The expense of having a plane off the line long enough to do the refitting is tremendous," says Roy Beiber, senior avionics engineer for USAir. In 1985 that company revamped its fleet with digital boxes that recorded the five required parameters but were capable of recording more with aircraft rewiring. The rewiring will be necessary within two years—both the FAA and the International Civil Aviation Organization have recommended that large passenger aircraft record 32 parameters.

Not everyone feels that increasing the data is essential. "Maybe for some of the newer planes it's a good idea," Beiber says, "but some operators have felt that the NTSB isn't going to learn that much more than they already know about the older planes just because they carry more parameters."

The practice of spending hours standing in front of a tower of sound equipment repeatedly listening to sounds of airplanes breaking up on cockpit voice recorder tapes is a relatively new one. When voice recorders became required equipment in the 1960s, no one was trained to listen for the minutiae on the tapes that might be important. No one, in fact, really knew what he was listening for.

Much of the work of figuring out the system fell to Paul Turner, a former fighter pilot who had survived a year as a POW after his F-86 was shot down over North Korea. A one-time Air Force test pilot with a penchant for gadgets, he had been working as an FAA inspector when the career change came. By the time he retired Turner had heard it all. He listened to laughter and obscenities, and he discreetly ignored intimate details of personal lives. He even heard pilots talking about fatal crashes just moments before their own. But he largely dismisses the notion that his job was gloomy, pointing out that human voices were only part of what he listened for.

Often it is peripheral sounds, not voices, that provide the clues to a mishap. Explosive decompression or fire warnings may be heard on a voice recorder tape, but often that merely exposes a fact instead of offering an explanation. An Air Canada DC-9 that caught fire and was forced to land in Cincinnati in 1983, for example, recorded the fire bells. But it also played back an odd noise that was eventually traced to restroom circuit breakers popping behind the cockpit—a clue to the cause of the fire. Turner once calculated precisely where lightning had struck an airplane, using only voice recorder tapes and a knowledge of the speed at which sound travels. Jim Cash was able to calculate the takeoff speed of the Continental DC-9 that crashed in Denver last November by listening to the sound of the nose wheel.

But sometimes a tape reveals no obvious details—or worse, raises more questions than it answers. For instance, the recording from a Midwest Express DC-9 that crashed in Milwaukee in 1985 picked up a puzzling noise that may be related to the cause of the accident, but it's never been identified. Laments Turner, "A lot of times you'll hear a pilot say, 'Gee, what's that? I'd better take care of it.' And then they go in. You can listen to it over and over and you'll never figure out what he was looking at."

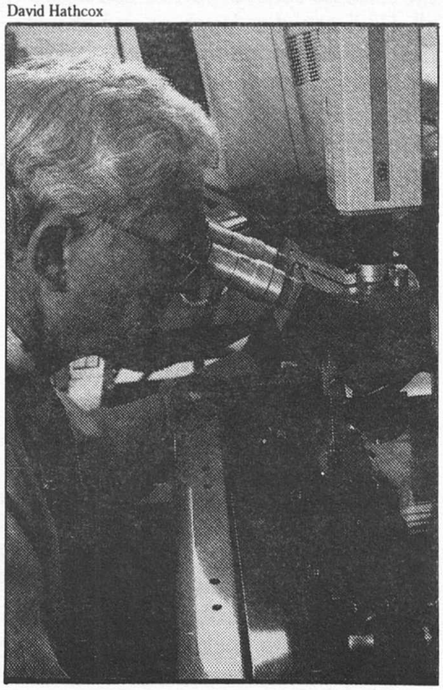
And then they go in. "You have to separate yourself from the idea of death and look at it as a job," says Turner. "I wouldn't say you ever exactly get used to it, but you can't let it interfere. Yes, there are feelings of sadness and remorse and it gets to you sometimes. You sit there listening, knowing what's going to happen, and you think, *God, don't do it.*"

Black box engineers will tell you that swift advances in their field—and in aviation overall—are saving lives. "The electronics are getting better all the time," says Monty Montgomery, chief of the engineering services division at the NTSB. "Planes are becoming more alike, more controllable, and easier to fly." What keeps the investigators so busy, they say, is that unfixed point where the lines of technology and human action intersect. "If you spend enough time looking at the evidence you'll see that in 90 percent of the cases an incident's cause is due to pilot error," says Grossi. "The airplane may screw up in some way but the pilot

The Charlotte Observer

NTSB investigations aren't limited to major disasters. The black boxes also provide clues about incidents like this 737 mishap in North Carolina.

David Hathcox



Billy Hopper of the NTSB specializes in data from scratch recorders. These older recorders are being replaced by the more advanced digital kind.

makes the situation worse." An unscientific conclusion perhaps, but enough investigators shared it that the NTSB formed a Human Performance Division, a group of psychologists who attempt to explain and improve ways in which decisions are made on the flight deck.

"Ninety percent pilot error sounds like an awfully high number to me," says Andy Yates, a retired 747 captain for United Airlines. Yates is a former chairman of the Airline Pilots Association's Flight Recorder and Voice Recorder Committee, set up in 1967 to counter what pilots saw as a data evaluation system open to capricious interpretation. "We were flying west one night doing a little celestial navigation," Yates recalls. "I saw the constellation Sirius descending and said to the crew, 'Look, the dog's going down.' Immediately I thought, *Now what the hell would the investigators make of a comment like that?*"

Still, he says, the system has come a long way. "A few years ago nobody would even acknowledge there was such a thing as wind shear. 'Can't find anything wrong with the plane,' they said. 'Must be pilot error.' Suddenly the data started showing it."

Black box investigators are proud of their contributions to the unraveling of the wind shear mystery (see "The Might of the Microburst," August/September 1986). The black box has also spurred improvements in airplane design, flight deck operation, runway procedure, and even runways themselves.

The causes of some accidents, however, are still not known, often because the airplanes involved weren't carrying recorders. Most private aircraft don't carry them. Neither do most commuter airplanes.

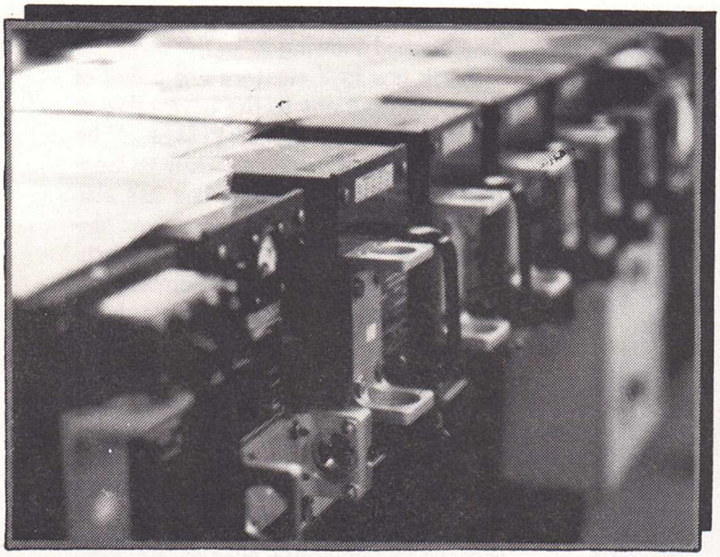
That situation is changing: last February, following a series of unexplained crashes by commuter aircraft, the FAA took steps to require cockpit voice recorders on commuter airplanes and helicopters seating six or more, as well as 17-parameter flight recorders on airplanes seating between 10 and 19 people and 32-parameter boxes on aircraft seating 20 to 30.

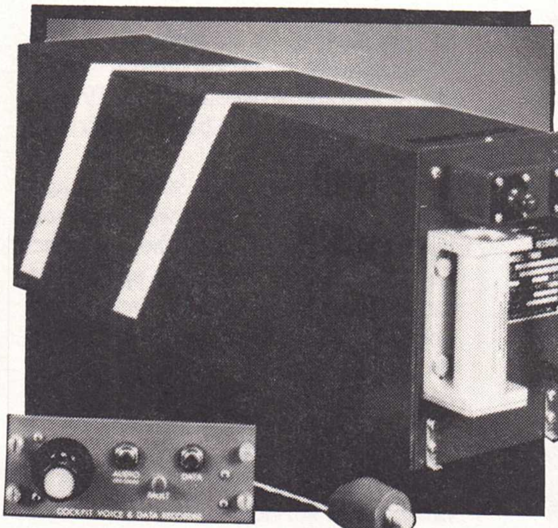
Officials at the NTSB, which has long lobbied for the changes, were pleased, but not everyone shares their satisfaction. John Fredericksen, a spokesman for the Regional Airline Association, doesn't foresee much difficulty fitting the airplanes with voice recorders but believes the extensive rewiring necessary to add data recorders will be "a very expensive endeavor. In many cases," he says, "the airplanes will be taken out of service."

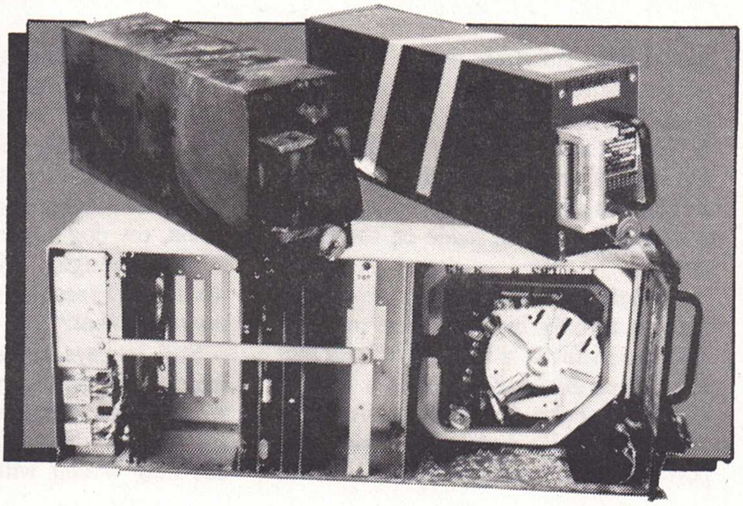
Other developments for the next generation of recorders may include telemetry—recording flight data from the ground. And video recorders may one day be installed in cockpits to help identify suspects in hijacking cases. Yet another possibility is a rugged optical storage system—much like compact discs—that can hold thousands of bits of information. Some speculate that ejectable-on-impact flight recorders would end retrieval problems, such as the failure to recover Korean flight 007's recorders after the airplane was shot down by the Soviets in 1983.

Whatever happens, NTSB investigators don't anticipate going out of business anytime soon. They will continue peeling open flight recorders, looking for the answers only the black boxes can provide.

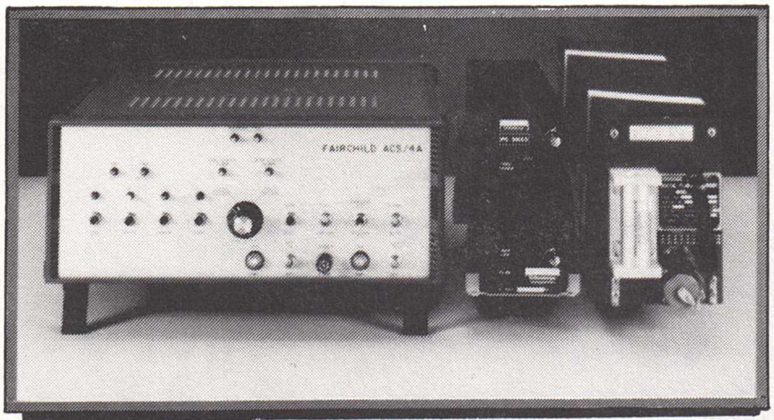
CELEBRATING THE COMPLETION OF OUR

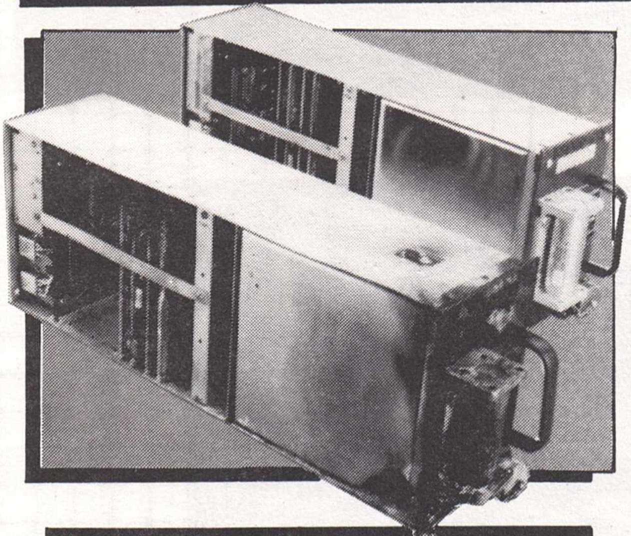


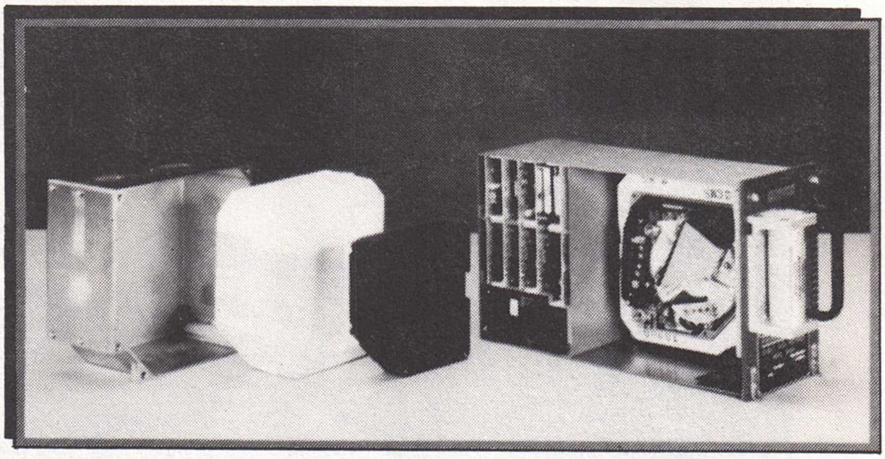


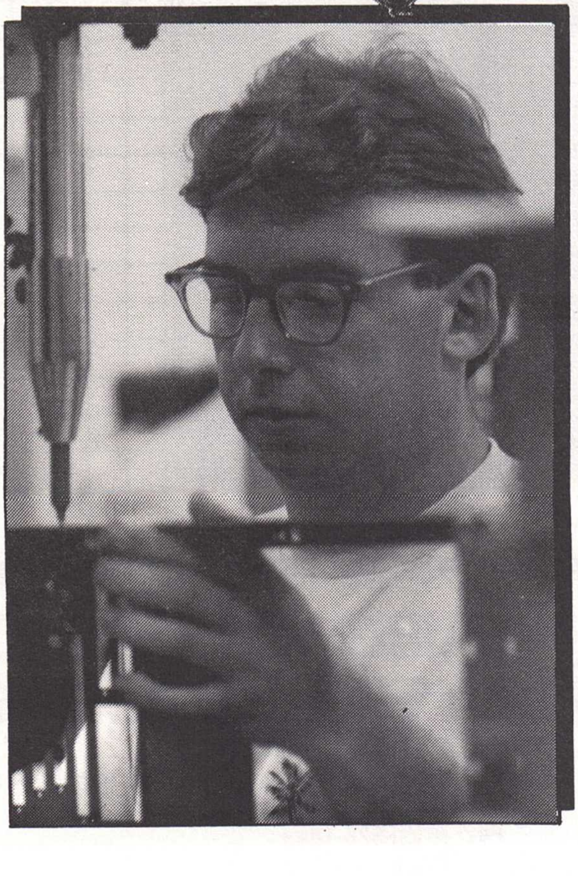


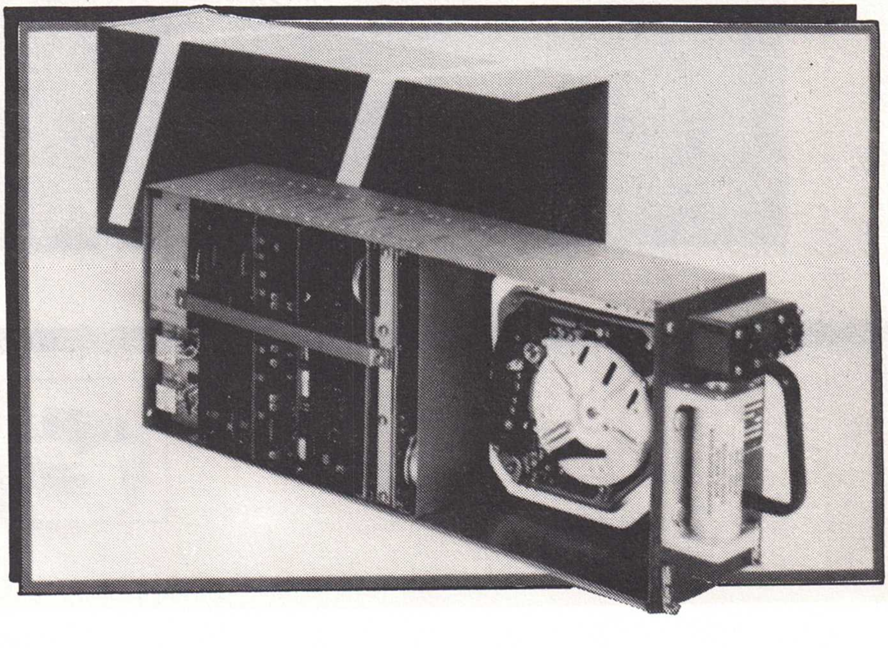
20,000th BLACK BOX UNIT MANUFACTURED











BY FAIRCHILD WESTON IN SARASOTA, FLORIDA.

FAIRCHILD WESTON SYSTEMS INC.

FAIRCHILD WESTON Schlumberger

DATA SYSTEMS DIVISION

P.O. Box 3041, Sarasota, Florida 34230-3041

(813) 371-0811 • Telex: 4947160

Fax: (813) 378-1893