Since introducing the first FAA-approved flight data recorder on a Boeing 707 (upper left) in 1958, Lockheed Aircraft Service (LAS) has produced nearly 4000 of various types for commercial airlines and the U.S. Air Force—more than 40 percent of the flight data recorder market in the Free World. Commercial aircraft transport types currently operating with LAS recorders include many foreign-built transports, such as the A.300 and the Concorde, and essentially all the U.S.-built transports, represented by the Lockheed L-1011 TriStar (upper right). Future applications include the BAC 146, and the Boeing 757 and 767 (lower right). Current and future military uses range from the Lockheed SR-71 to U.S. Army helicopters and USAF cargo transports, including the Lockheed C-5A Galaxy (lower left).

Aircraft accidents, although relatively infrequent in modern times, are a subject of great concern to operators and users of transport aircraft throughout the world. They impose a number of hardships on society, ranging from mere inconvenience to major tragedies involving injury, and loss of life and property. While a large variety of preventive measures have been employed, unfortunately, total prevention has not been possible. Meanwhile, the overall activity of accident investigation, and particularly the role of the airborne flight recorder, are of vital concern to aviation. The accurate recording of critical factors of aircraft performance has proven invaluable in
MODERN AIRCRAFT ACCIDENT INVESTIGATION EQUIPMENT AND TECHNIQUES

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Aircraft accident investigation in helping to pinpoint the cause of an accident and in instigating measures to prevent future recurrences.

AIRCRAFT FLIGHT RECORDER HISTORY AND DEVELOPMENT
In August 1957, the United States Civil Aviation Board adopted Civil Air Regulations mandating that crash protected flight data recorders (FDR) be installed on all large United States passenger aircraft operated above 25,000 feet altitude. Lockheed Aircraft Service Company delivered the first such recorder which met the stringent requirements for crash survivability in June, 1958, for installation on a PAN AM Boeing 707.

This FDR, the LAS Model 109-C, Figure 1, was a sphere about 15 inches in diameter with an equatorial mounting flange located where the top and bottom halves of the sphere fit together. It incorporated mechanically and electrically operated styli, which scribed a permanent record of pressure altitude, indicated air speed, magnetic heading, vertical acceleration, and microphone operation, with a time base, on aluminum foil, 2½-inches wide and 0.001-inch thick. One spool of the foil medium recorded up to 200 hours of operation. Because the traces were embossed, the foil recording medium could only be used once.

A later version of this FDR, the LAS Model 109-D, Figure 2, operates in essentially the same manner; however, the container is rectangular and suitable for installation in a typical radio rack. In 1969, the U.S. Federal Aviation Authority issued amendments to the Federal Aviation Regulations to increase the amount of recorded flight data required for all new, large airplanes that were turbine engine powered, or certified for operation above 25,000 feet altitude, for which type certificates were to be issued after September 30, 1969. These regulations required the recording of over 20 parameters which were considered to be of major importance during the investigation of aircraft accidents.
A new type of recorder, the LAS Model 209 Digital Flight Data Recorder (DFDR), Figure 3, in use today on wide-body, turbine-powered aircraft, uses magnetic tape as the recording medium and records a much wider range of aircraft performance and flight data. A Flight Data Acquisition Unit (FDAU) installed in the DFDR-equipped aircraft is supplied with aircraft data in analog form from various sensors and transmitters on the aircraft. The FDAU converts this information to digital form and transmits it to the DFDR for recording. The LAS Model 209 DFDR records data on six sequential tracks using ¼-inch, 1-mil mylar magnetic recording tape. During operation, one track is recorded at a time in a predeterminated bidirectional sequence. When an end-of-tape is sensed, motor rotation is reversed and the recording electronics are switched to the next track. The total recording time for the six tracks is more than 25 hours, continuously updated, with oldest data being erased as new data are recorded. Tape speed is 0.37 inches per second with a data density of 2,076 bits per inch at 64 words (12 bits each) per second.

An additional feature of this recording system is its ability to record many more parameters than those necessary for accident investigation. This capacity can be used for the collection of data for such purposes as maintenance data gathering, crew performance monitoring, engine trend analysis, fuel flow management, etc. Depending on data sample rates, 80 or 90 parameters can be recorded when additional monitoring programs are desired.

The Model 209 DFDR has been in service since 1971. There are presently over 1,000 units in service of which approximately 800 are installed in aircraft flying about 10 hours per day, or roughly 3,000 hours per year per unit. In excess of 7 million hours of operation have been accumulated by the LAS units in service. Backed by this history of excellent operational experiences, LAS has embarked on a program to improve and update the electronics of the DFDR. This new microprocessor-controlled Model 209 DFDR will be ready for service in January, 1982.

A derivative of the Model 209 DFDR, the Model 319 Flight Data Recorder System (FDRS), has been in service since 1977. This FDRS combines the functions of the FDAU and DFDR into a single ¾-ATR-size package. The FDRS was designed expressly for use in business and commuter aircraft where space and weight are paramount factors. A limited parameter FDAU is installed in the electronics section of the recorder to provide signal conditioning. Other parts of the recorder (tape deck, protective housing, etc.) are identical to those in the Model 209 DFDR.

**Recorder Survivability Standards**

In order to ensure a high probability that the recorders used for accident investigation will survive the accident, the United States Civil Aviation Board has established minimum requirements for the development and testing of those recorders. These requirements were issued as Technical Standard Orders: TSO-C51 in August 1956, and TSO-C51a in December 1965. In their letter WE-104/8105 dated 15 January 1971, the FAA granted approval for LAS to identify the Model 209 DFDR as conforming to TSO-C51a, paragraph 37.130, Minimum Performance Standards for Aircraft Flight Recorder. This approval was granted after LAS successfully demonstrated that the Model 209 met the following:

A. Vibration: The recorder operated properly when subjected to vibrations of 5 to 500 cycles per second, at 0.036 inch double amplitude and 10g acceleration, in 15-minute cycles for a period of 1 hour in each axis.

B. Impact Shock: The intelligence on the record medium remained intact after the recorder was subjected to half sine wave impact shocks applied to each of three main axes having a peak acceleration magnitude of 1,000g with a time duration of at least five (5) milliseconds.

C. Penetration Resistance: The intelligence on the record medium remained intact after the recorder had been subjected to an impact force equal to a 500-pound steel bar dropped from a height of 10 feet to strike each side of the recorder in the most critical area. The point of

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**FIGURE 1** Lockheed Flight Data Recorder Model 109-C  
**FIGURE 2** Lockheed Flight Data Recorder Model 109-D
contact on the bar could have an area no greater than 0.05 square inches. LAS used a conical tip with a tip radius of 0.25 inches.

D. Static Crush: The intelligence on the record medium remained intact after the recorder was subjected to a static crush force of 5,000 pounds applied continuously, but not simultaneously to each of three main axes for a period of five minutes.

E. Fire Protection: The intelligence on the record medium remained intact after the recorder was exposed to flames of 1100°C, enveloping at least 50 percent of the outside area of the case for 30 minutes.

F. Water Protection: The intelligence on the record medium remained permanent and reproducible after immersion in sea water for 36 hours. TSO-C51a further specifies that tests B through F shall be made in the sequence shown on the same recorder without the need for repairs. There were other requirements for temperature, humidity, altitude, radio interferences, and magnetic effect, but those listed above are those most affected by an aircraft accident.

In October 1973, the British Civil Aviation Authority (CAA) issued the third draft of Airworthiness Division Specification No. 10 covering flight data recording systems operating environment and record survivability requirements for certain categories of United Kingdom registered aircraft. Significant differences existed between this specification and TSO-C51a requiring additional testing of the recorder and record medium. LAS successfully demonstrated that the Model 209 DFDR could also meet these additional requirements.

A. Fluids (except seawater): The intelligence on the record medium remained intact after being immersed for 24 hours in each of the following fluids:

- Aircraft fuel
  - JP-1 (kerosene)
  - JP-4
- Lubricating oil
  - Shell 555
- Hydraulic fluid
  - Skkydrol 500
- Fire extinguishing fluid
  - Glycol + 62% water

B. Seawater: The intelligence on the record medium remained intact after immersion in seawater for 32 days.

C. Vibration: The recorder operated properly when subjected to vibration conditions of 1.05 Hz, 20-inch total excursion for one minute in the vertical, horizontal, and longitudinal axes.

In May 1975, the Radio Technical Commission for Aeronautics (RTCA) and the European Organization for Civil Aviation Electronics (EUROCAE) jointly released documents covering the environmental test criteria and procedures for electronic equipment and instruments for the whole spectrum of aircraft from Light General Aviation Aircraft and Helicopters through the Jumbo Jet and Supersonic categories. These documents are RTCA DO-160 and EUROCAE WG 14-1/75. All recorders built to satisfy the requirements of TSO C51a are tested in accordance with these documents.

The crash of an Air India 747 in the Arabian Sea west of Bombay on New Year’s Day, 1978, subjected a LAS Model

FIGURE 3
Lockheed Flight Data Recorder
Model 209

FIGURE 4
Recovered B.747 Flight Data Recorder (LAS Model 209 DFDR) as Received at U.S. National Transportation Safety Board (NTSB)
209 DFDR to a true test of its survivability. Located on the muddy seabed, it had broken free of its mounting rack and the drive motor and electronics section were missing. However, although it apparently had been exposed to severe impact, fire, and immersion in salt water, the crash protected section was in very good condition. Still immersed in water, the recorder, Figure 4, was flown to the National Transportation Safety Board in Washington, D.C., where it was successfully played back, providing valuable data toward determining the cause of the accident. Although Lockheed flight data recorders had been aboard other aircraft that had been involved in accidents, including the 747 accident in Tenerife in 1977, this was the first incident in eight years that subjected the Model 209 DFDR to such an extreme test.

POST-ACCIDENT RECORDER HANDLING

In cases where an accident exceeds the “standard” crash defined by the FAA document TSO-C51a, it is possible that the recorder would be in other than perfect condition. In this case, a very important part of post-accident recorder handling would be the exercise of extreme caution to prevent further damage to the recorder and recording medium.

Photographs of the wreckage; a complete map or description of the area and wreckage; and location of the recorder, with reference to the wreckage, are invaluable aids. After recovery, the recorder should be sealed in a container, which will retain its condition when found, until such time that qualified personnel can continue with the data recovery.

If found in water, especially sea water, the recorder should be allowed to drain, then be resubmerged in fresh water, drained, and finally transported in a container of fresh water. This will help protect the iron oxide record medium from the harsh environment of drying salt water.

Again, transportation of the recorder should be handled with as much care as possible to preclude adding to any possible damage already incurred. Cushioning of the recorder in a container to prevent additional shock protection from heavy magnetic fields, and preservation of recorder attitude during transportation are also important considerations.

High on the list of critical phases in accident investigation is the handling of the recording medium. This should only be attempted by qualified personnel.

In the case of a foil-type FDR, the procedure is the same for both major accidents and minor incidents. In either case, the foil must be removed from its holder, cleaned as necessary to remove foreign particles or contamination, and then read out manually point-by-point, with an optical readout device.

In the case of the magnetic tape DFDR, the data recovery procedure varies with conditions. If the recorder is undamaged as is normally the case in an investigation of a minor accident or incident, there is no need to handle the tape since the DFDR itself can be used for the playback. With the LAS Model 209 DFDR, playback can even be accomplished without removing the DFDR from the aircraft by making a copy of the DFDR record, with a LAS Model 235 Copy Recorder, and using this copy recording for the investigation. If the recorder has been damaged,
but the tape deck of the LAS Model 209 DFDR is undamaged, there is still no need to handle the tape, since it is possible to play the tape deck as a unit.

However, if the tape deck shows sign of damage, or contamination by salt water or aircraft fluids, it is best to remove the tape from the deck reels, rewinding carefully on new plastic reels. Salt water and many other fluids can be removed from the tape by carefully rinsing the tape in fresh water several times and drying with soft tissue pads. Hydraulic fluid and methyl bromide can be removed from the tape by carefully rinsing the tape in alcohol, then fresh water, finally drying with soft tissue pads. Lubricating oils, JP-1 and JP-4 fuel contaminated tape can be rinsed in mineral spirits followed by fresh water rinse and soft tissue pad drying. In all cases, extreme caution is necessary to keep from scratching or otherwise damaging the oxide surface. The tape can then be played back on a tape reader, such as the LAS Model 226A.

Experience has shown that data can even be recovered from wrinkled tape, if it is carefully flattened. We have successfully flattened wrinkled mylar magnetic tape with a warm electric iron.

In all cases, the playback is accomplished through a flight data reduction station, which can produce output reports of the aircraft data in a variety of formats. The recorded digital data can be presented in a graphic value-versus-time form on an 8-channel strip chart recorder; or with the necessary computer hardware and software, the data can be presented in a tabular second-by-second “engineering units” printout of the value of each parameter.

Readout of flight data from the DFDR is much faster and more accurate than from the foil recorders and the variety of output formats possible greatly enhances its usefulness as an investigative tool.

Data Recovery Procedures

As previously mentioned, foil-type FDR flight data readings are accomplished by optical readout. The United States National Transportation Safety Board (NTSB), Washington, D.C., has an optical readout machine of high accuracy, which was built to their specifications, Figure 5. This machine contains a fixed platen for mounting the foil medium, a moving microscope for following the recorded traces, and a flexible fiberoptic light source. The microscope has a magnification range of 35 to 200 and can accommodate a polaroid pack camera to photograph segments of the traces through the microscope. Electronic counters display the X and Y coordinates as the microscope is guided along the scribed traces. These values are then plotted on a graph of appropriate scales for analysis of aircraft operation. Radio transmission indications are also plotted as a parameter to be used in correlating the cockpit voice recorder transcript with the flight recorder readout.

Digital flight data recorder readouts are accomplished on a flight data reduction station. These stations can range from a simple analog system consisting of a tape reader, input control panel, select and display panel, and an 8-channel strip chart recorder, to multibay computerized digital systems with tape reader, input control panel, reformatter, 9-channel magnetic tape...
units, CRT terminal, disk operating system, and high-speed printer/plotter, Figures 6 and 7.

The analog type of system accepts inputs from a DFDR or a copy tape, these inputs being in the form of Harvard Biphasic at normal record speed (766 bits/second) or 32 times record speed (24,576 bits/second); squared data at 0 and +5V levels; and unsquared data from 4V peak-to-peak to 10V peak-to-peak. This system will search for specific data; display GMT, selected data word, and documentary data; convert Harvard Biphasic serial data to a synchronized parallel binary data sequence; then convert the analog data for the strip chart recorder. Some systems even automatically start the 8-channel strip chart recorder when a requested preset data value has been obtained.

The digital type of system will accept the same types of input sources. This flight data is then reformatted and transcribed onto a 9-track computer-compatible magnetic tape. The system will read the 9-track computer-compatible tape, and extract and store selected portions on a disk. It will read the disk files, convert the selected data to engineering terms, and print or plot the data as required. Communication with the computer can be entered via CRT terminal, or punched card, with the CRT normal. Output of the system can be a digital "engineering units printout" or a single-channel analog-style plot.

While both types of systems will accept the same inputs, the output of the first only provides a flight profile and requires manual measurement and annotation, while the second automatically provides a precise cross section of all parameters of a flight in a second-by-second listing.

### Data Recovery Problems and Solutions

Under perfect recording conditions, the bit pattern recorded on the tape is stable as represented in Figure 8. During readout, the playback heads differentiate the recorded magnetic flux pattern to produce the pattern shown in Figure 9. Electronic circuitry then provides necessary wave shaping to reproduce the recorded pattern as shown in Figure 10. The recording and readout of data is, however, dependent upon mechanical tape decks with rotating capstans, guides, and reels. These produce some uneven tape motion, or jitter, across the heads, as illustrated in Figure 11. Large shocks or buffeting, as may occur in incidents or accidents, can further aggravate this condition.

The use of a pulse of fixed length, as provided by a one-shot in the data recovery equipment, started at the beginning of each bit cell, can detect the difference between "Is" and "Os" by the presence or absence of the characteristic level transition of a "1" during the one-shot period. As long as all transitions occur within that time period, no errors occur. If, however, the jitter increases to a point that a "Is" transition occurs outside the one-shot pulse, or a "O" were so short as to complete the bit period within the one-shot pulse, errors can occur. Making the one-shot timing adjustable so that it will fall at the optimum center of the decision window makes it possible to eliminate errors at specific spots, even though it may create them elsewhere. By making several runs through a specific area of interest at several different one-shot settings, the entire record can be obtained.

Carrying this adjustment process one
LAS is currently working on hardware and a software program which will transfer all data recorded regardless of synchronization. Once transferred, the computer will read the data normally up to the point where the dropout occurs, search for the next sync word, and read out the data from that sync word in reverse back to the dropout, automating the manual conversion process.

Other computer programs to facilitate data recovery and simplified system hardware to decrease costs to potential customers are also under development.

**SUMMARY**

The use of modern flight data recorders and associated investigative procedures has led to a significant reduction in the number of aircraft accidents. Critical records of aircraft performance are invaluable in aircraft accident and incident investigation and help prevent recurrence in the future. The DFDR's ability to record upwards of 80 to 90 parameters extends its usefulness beyond accident investigation to the collection of data for maintenance data gathering, crew performance, and engine trend analysis, fuel flow management, etc.

Data recoverability can be accomplished on systems which provide outputs ranging from simple flight profiles, requiring manual measurement and annotation, to automatic computerized second-by-second listings of all recorded parameters. LAS is a leading supplier of airborne flight data recorders and data playback stations and has contributed several special features to the NTSB digital system such as:

- Supersync or super synchronization mode of operation wherein acquisition of any one sync word causes an in sync condition. In addition, prior to the end of the subframe, a window is opened which enables the circuit to look for the next sync word up to 8 bits early (normal sync mode requires two sequential sync words spaced exactly 768 bits apart).

- A wide band filter that can be switched into the circuit to aid in recovering data that exhibit large amplitude frequency modulations.

-A BITDUMP mode of operation which permits the transfer of a continuous stream of data bits from the DFDR tape directly to computer memory regardless of sync condition. Once a switch is enabled, data transfer begins immediately upon the system's recognition of a single subframe number 1 sync word and continues until 12,000 bits have been stored in computer memory.

A special "interface/control" panel which permits data recoverability from any manufacturer's recorder on one single data recovery system. LAS continues to search for new technology and technology applications which will increase the effectiveness of the recorder and the data recorded to provide even safer airborne transportation.