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THE STATUS OF FLIGHT RECORDERS IN MODERN AIRCRAFT

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INTRODUCTION

The National Transportation Safety Board (NTSB) is responsible for investigating and determining the cause or probable cause of civil aviation accidents.[1] All large[2] aircraft in air carrier operations[3] and air taxi operations[4] must be equipped with an approved flight data recorder (FDR) and a cockpit voice recorder (CVR). Any aircraft type certificated after September 30, 1969, that is required to carry an FDR must carry an expanded parameter FDR. This includes the wide-bodied B-747, DC-10, and L-1011 aircraft. NTSB Chairman Webster Todd recently announced[5] that he would favor a recommendation asking the Federal Aviation Administration (FAA) to require recorders on corporate jets.

COCKPIT VOICE RECORDERS

The CVR has been required equipment by United States Federal Aviation Regulations (FAR) since 1966.[6] The CVR is a four-channel, crash-survivable type unit that records all radio communications to and from the aircraft, interphone communications, sounds from the flight deck, and signals identifying navigation and approach aids for a period of at least thirty minutes. The CVR

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[1] 49 C.F.R. § 800.3 (1976).

[2] The Federal Aviation Administration is now in the process of redefining "large." *See* notes 31-34 *supra* and accompanying text.

[3] 14 C.F.R. § 121.343 (1977).

[4] 14 C.F.R. § 135.2 (1977).

[5] Aviation Daily, Oct. 5, 1976, at 190.

[6] 14 C.F.R. § 121.359 (1977).

unit must be mounted as far aft as practicable in order to maximize its survival in case of a crash.[7] Minimum performance standards for CVRs used on United States civil aircraft are given in Technical Standard Order (TSO) C84.[8]

Many times the information recorded by the CVR provides excellent clues to the cause of an accident. The flight crew's conversation in the cockpit immediately before the occurrence usually gives at least a hint of the problem, whereas such information is seldom broadcast to air traffic control. A good example of the CVR providing clues to the cause of an accident is found in the NTSB accident report on the Eastern Airlines L-1011 crash near Miami, Florida, in December 1972.[9] The CVR record indicated that the flight crew became so preoccupied with a malfunction of the nose landing gear position indicating system that they failed to notice that the autopilot altitude hold had disconnected, allowing the aircraft to descend and crash. The aircraft was destroyed, and ninety-four passengers and five crew members received fatal injuries.

The recording of cockpit conversations by the omnidirectional cockpit area microphone, known as the CAM, is of extremely poor quality in many aircraft. The cockpit voice recorder laboratory at NTSB is equipped with a considerable amount of modern electronics readout equipment to extract information from the tapes, but it has sometimes been so difficult to determine what was being said that the readout group has spent several days repeatedly listening to sections of a tape before the preliminary transcript was issued. Even then, there has been disagreement as to what was said, and such areas of the transcript are so marked. In addition, the transcript always carries a warning which says:

> The reader of this report is cautioned that the transcription of a CVR tape is not a precise science but is the best product possible from an NTSB group investigative effort. The transcript or parts thereof, if taken out of context, could be misleading. The attached CVR transcript should be viewed as an accident investigation tool to be used in conjunction with other evidence gathered during the

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[7] 14 C.F.R. § 25.1457 (1977).

[8] 14 C.F.R. § 37.190 (1977).

[9] Accident Report, NTSB-AAR-73-14, Eastern Air Lines at Miami, Fla. (Dec. 29, 1972) (available from National Technical Information Service [NTIS], Springfield, Va. 22151).

investigation. Conclusions or interpretations should not be made using the transcript as the sole source of information.

The following are among the special devices used in the CVR lab to obtain a tape transcript:

1. two four-channel tape recorders with continuously variable speeds ranging from seven-eighths to fifteen inches per second,
2. a four-channel professional Crown preamplifier and amplifier system (high power and high fidelity),
3. a variable speed, frequency compensated cassette recorder which allows tape playback speeds to be slowed by as much as one-half or increased by a many as two times without pitch changes in the voice signal,
4. a single channel Burwen noise filter that has a variable spectral window for dynamically filtering noise outside the voice range,
5. a two channel Allison volume compression/expansion device that allows either maintenance of the same signal level for widely varying speaker volumes or separation of voices by suppression of the volume of one voice,
6. four notching filters with extremely narrow bandwidths for blocking out narrow-band noise,
7. a graphic spectrum equalizer shaping filter,
8. a Sony videotape system for CVR tape timing purposes,
9. a Voiceprint machine that is used mainly for repeatedly playing two second segments of the CVR tape (the scanner feature) and for identifying cockpit audible warning signals such as the altimeter warning horn.

Questions arise as to why the CAM channel is of such poor quality, and what can be done to remedy the situation. Many of the problems are caused by inadequate CVR maintenance, *i.e.*, worn or dirty recording heads, improperly adjusted channel gains, noisy channels (electronic noise), and dead channels. The remedy is obvious in these situations.

Audio interference is another problem on the CAM channel. In certain aircraft, engine and air noise interfere with speech recording. However, these noises can sometimes be useful in themselves, as will be demonstrated later. The NTSB has already recommended to the FAA that two directional microphones be used rather than a single omnidirectional mike. This would help filter out sounds eminating from outside the cockpit. The FAA has issued a Notice of Proposed Rulemaking (NPRM) on the subject[10] and solicited comments from interested parties. It would appear that the NPRM is currently in a state of limbo.

In certain aircraft, the cockpit radio speakers are mounted too close to the CAM, and when the speakers are used instead of the headsets, cockpit conversations are rendered unintelligible. Directional mikes help in this case, but the use of headsets would eliminate the problem. Unfortunately, many flight crew members prefer to use the speakers.

The NTSB has made use of spectrum analysis of engine noise recorded on the CAM channel to determine engine rotation frequencies when such data were available on the CVR tape.[11] The amount of thrust generated by the engines may be derived from these data. This technique, however, is limited by the frequency response of the recording system (nominally 300-3500 Hertz), the proximity of the engines (rear-mounted engines are not audible), and the amount of noise generated by the engines.

The NTSB recently purchased a digital signal processor/fast Fourier transform machine to provide in-house capability for sound frequency analysis. Such work was started at the NTSB in a joint effort with the General Electric Company in 1966.

Flight Data Recorders

There are two types of flight data recorders. The older oscillographic recorder is the most common unit in use in the United States today. A new unit, called the digital flight data recorder (DFDR), is an expanded parameter recorder, and will be in more widespread use as today's aircraft are supplanted by aircraft certified after September 30, 1969.[12]

Oscillographic Flight Recorders—oscillographic recorders are FDR's that preserve their data by engraving altitude, airspeed, magnetic heading, and vertical acceleration[13] traces on metal foil as

[10] 40 Fed. Reg. 23,054 (1975).

[11] Accident Report, NTSB-AAR-73-8, Mohawk Airlines at Albany, N.Y. (Mar. 3, 1972). Accident Report, NTSB-AAR-73-16, United Air Lines at Chicago-Midway Airport, Ill. (Dec. 8, 1972) (both available from NTIS).

[12] 14 C.F.R. § 121.343 (1977).

[13] *Id.*

a function of time. A binary stylus also records radio transmitter (microphone) keying so that the FDR data can be matched in time to CVR data.[14]

Each data trace engraved on the FDR foil is read in the NTSB laboratory by placing the foil under a 35-200 power microscope, aligning the cross hairs on selected points of the trace, and taking readings of the X and Y coordinates of those points. If a trace varies rapidly in time, many points must be read in a given time interval to accurately reproduce the data trace. If the trace has variations or is constant for a long time interval, correspondingly fewer readings are taken.

The X-Y coordinates are transmitted to and temporarily stored on a magnetic disk in the NTSB's computerized data reduction station. When all X-Y coordinates are read over the pertinent time period for traces desired, a computer program is called. This transforms the data from distances on the foil in inches to the parameter values. For example, X values in inches from a reference point are transformed into elapsed time in minutes and seconds, and Y values in inches from a reference point are transformed into appropriate units (feet if the parameter is altitude, knots if it is airspeed, etc.).

The data are then plotted so that the recorded information is finally presented in graphical form. FDR data in NTSB accident reports are presented as plots of altitude versus time, airspeed versus time, and so on.

FDR survivability under crash impact forces and fire, as well as maximum recording time intervals, ranges for recorded parameters, and allowable record errors under test conditions are given in detail in TSO C51a.[15] Briefly, allowable recording errors under test conditions for the various parameters are:

Time	:	±1% in 8 hours
Altitude	:	±100 ft. at sea level to ±700 ft. at 50,000 ft. (room temperature)
Airspeed	:	±10 knots at room temperature
Heading	:	±2°

[14] 14 C.F.R. § 25.1459 (1977).
[15] 14 C.F.R. § 37.150 (1977).

Vertical Acceleration: ±0.2G in a stabilized condition, ±10% of the acceleration following a single, triangular, acceleration pulse of 0.5 second duration or greater

As with the CVR, FDRs sometimes do not yield data because they are not properly maintained. There have been at least four cases in which the foil medium was depleted before the accident occurred, at least two cases where a leak in the static pressure line supplying the FDR altitude and airspeed sensors caused faulty readings in these parameters, and at least one case where the static pressure line was not connected to the recorder at all. It should be noted that the FDR pilot and static systems are completely independent of those supplying information to the cockpit instruments.

Other problems associated with poor maintenance include gaps in recorded traces caused by such things as high clutch torque on the magazine, dirty scribe rollers, incorrect threading of foil, and maladjusted takeup drive switch. Inadequate stylus pressure adjustment has resulted in either faint or nonexistent traces. These are merely samples of the problems associated with FDR. The statistics are fully developed in the NTSB's special study on its experience wtih FDRs from 1960 through 1973.[16]

Digital Flight Data Recorders—the DFDR records digital information on a crash and fire protected magnetic tape.[17] Most expanded parameter recording systems used by United States airlines follow the specifications outlined in ARINC Characteristic 573,[18] although Trans World Airlines follows ARINC Characteristic 563.[19]

The DFDR stores numerical data on magnetic tape, as opposed to the FDR, which stores engraved oscillographic traces on a foil medium. The mandatory flight parameters to be recorded are: time, altitude, airspeed, vertical acceleration, lateral acceleration or sideslip angle, heading, pitch and roll attitudes, pitch trim position,

[16] NTSB Special Study, NTSB-AAS-75-1, Flight Data Recorder Readout Experience in Aircraft Accident Investigations 1960-1973 (May 14, 1975) (available from NTIS).

[17] 14 C.F.R. § 37.150 (1977).

[18] Mark 2 Aircraft Integrated Data System (AIDS Mark 2), ARINC Characteristic 573, Aeronautical Radio, Annapolis, Md. (Sept. 8, 1972).

[19] Mark 1 Aircraft Data System (AIDS), ARINC Characteristic 563, Aeronautical Radio, Annapolis, Md. (July 8, 1971).

control *or* control surface position for pitch, roll, and yaw, thrust of each engine, position of each thrust reverser, trailing and leading edge flaps or cockpit flap control positions, angle of attack (if recorded directly, and radio transmitter keying. A list of mandatory parameters, their ranges, accuracies, and maximum recording intervals is available in the Code of Federal Regulations.[20]

Some foreign carriers record as many as 90 to 100 parameters, although this number is well above that required by U. S. regulations. The DFDR stores twenty-five hours of flight data on a continuously-running magnetic tape. Data older than this are erased as new data are recorded.

Tape format should be briefly described.[21] Since most DFDRs record data in ARINC-573 format, that format will be described. Each second of recorded data is called a subframe; four subframes comprise a frame. The first part of any subframe is a synchronization (sync) word which lasts for 1/64 of a second and signals the start of the subframe and identifies it. Besides the sync word, each subframe consists of sixty-three other words, each 1/64 of a second in duration.

A given word slot in the subframe may contain the same parameter as in other subframes, or it may contain a different parameter in each of the four subframes, or it may contain the same parameter in every other subframe. Hence, a parameter may be recorded once per second, once every four seconds, or once every two seconds. For example, heading is recorded in word three of all subframes (once per second), whereas the thrust parameter of engine number one is recorded only in word thirty-three of subframe one (once per four seconds). Word thirty-three of subframe two contains thrust of engine two, and so on. Consequently, more than sixty-three parameters can be recorded by the DFDR in a given frame.

Another feature also greatly enhances the capacity of the recorder. Many aircraft parameters are of the on-off type, such as radio microphone keying, engine thrust reverser unlock and deploy;

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[20] 14 C.F.R. § 121.343 (1977).

[21] Address by C. Roberts, The Flight Data Recorder and the NTSB's New Data Reduction Station, Proceedings of the 5th International Seminar, Society of Air Safety Investigators, in Washington, D. C. (Oct. 1974) (available from P. O. Box 23510, Washington, D. C., 20024). *See* notes 18-19 *supra.*

and slat deployment. A single "bit" is needed to encode each on-off parameter.[22] Each data word slot is assigned a length of twelve bits, and twelve bits are recorded in a time period of 1/64 of a second. However, certain analog parameters require fewer than twelve bits to be adequately recorded because they require less resolution than other parameters (*i.e.*, ten bits instead of twelve). The two least significant bits of low resolution analog parameters may be omitted, and the vacant bit positions used to encode two on-off parameters.

It is necessary to record some parameters at a higher frequency than once per second because these may be very active at times. Vertical acceleration, for example, is recorded four times per second. Thus, four words per subframe (words thirteen, twenty-nine, forty-five, sixty-one) are assigned to vertical acceleration.

DFDR tapes are not as simple to read as FDR foil. The magnetic tapes are first played on special electronic hardware that amplifies the recorded signal, shapes it, recognizes the sync words, puts the data stream into computer compatible format (the data are recorded on the DFDR tape in a waveshape called Harvard biphase code[23] which cannot directly be recognized by an ordinary computer), and records it on nine track computer tape.

The NTSB's data reduction station presently consists of a PDP-11/40 minicomputer with 28-K parity core (soon to go to 128-K for greatly enhanced processing speeds), disk system, keyboard terminal, two nine track magnetic tape units, a high-speed printer/plotter, a high-speed paper tape reader and punch, and hardware specifically designed for the flight recorder laboratory. Specialized hardware includes two DFDR readers so the one-fourth inch tapes from each of the two United States DFDR manufacturers can be transcribed to nine track computer tapes without being removed from their crash-proof containers, a reel-to-reel tape deck so a one-fourth inch tape can be played in the normal manner if it becomes necessary to remove it from a damaged DFDR, a sync recognition system, a computer interface to reformat the Harvard biphase data stream into computer compatible format, an eight channel strip chart recorder, and an FDR interface

[22] "Bit" is short for "binary digit." A bit can either be 0 or 1. Using 12 bits, we can count from 0 to 4095.

[23] *See* note 18 *supra.*

for getting X-Y coordinate data from the foil-recorder reader into the computer.

The signal from the DFDR tape is transcribed to a nine track computer tape using the NTSB's data reduction station. The transcription process is begun by looking for a sync word. When one is found, the system in normal sync mode expects the next sequential sync word 768 bits later (64 words x 12 bits per word). Meanwhile, data from the subframe are preserved. If the next sync word is found, the transcription continues. If the next sync word is not found, the data transcribed are flagged with an asterisk in the data printout to indicate that the data are questionable.

After a transcription tape is generated, it is played back on a nine track tape machine which feeds the information to the computer. A program is called from a computer disk, which converts the taped data in raw form (numbers from 0 to 4095 for twelve bit words) into the parameter values originally transmitted to the recording system by the aircraft sensors. The program called depends upon the airline and the type of aircraft involved.

The numbers recorded on the DFDR tape are scaled data, not necessarily the parameter values themselves. For example, heading (h) on the American Airline DC-10 is obtained from the raw data value (x) by multiplying x by the scale factor 360/4096

$$h = \frac{360}{4096} x$$

Thus, a heading of 240° will be recorded as the base 10 number x = 2731 (the 12-bit number representing x is a binary (base 2) 101010101011 or an octal (base 8) 5253). The scaling equation is usually not so simple and depends on the specific parameter, the type flight data acquisition unit used by the airline, and the type of sensors installed in the aircraft.

The end result of a normal readout is a second-by-second listing of the data for as much of a given flight or flights as desired (the so-called engineering units printout), as well as a plot of all or selected data parameters versus time. The DFDR group chairman's factual report for aircraft accidents always contains the engineering units printout and a plot. DFDA data in NTSB accident reports are usually presented in graphical form.

Engineers have had problems in the past with DFDRs, but both manufacturers (Sundstrand Data Control of Redmond, Washington, and Lockheed Aircraft Service Company of Ontario, California) have significantly improved their designs since they were first introduced. In general, the redesigned DFDRs have given satisfactory results.

Since the digital recording system has come into use fairly recently, and is used on only a small fraction of the present U. S. fleet, DFDRs have not been included in the special study on experience with flight recorders.[24] In addition, there have been failures in the system—not necessarily in the DFDR itself. The digital recording system is very complicated. It depends on a large number of sensors, data transmitters, electronic components in the flight data acquisition unit and in the DFDR itself, plus the mechanical tape system of the DFDR.

In one recent case, the DFDR was operating during the accident sequence. However, the unit which fed the data signal to the DFDR had ceased operating approximately one week before the accident. This failure had gone undetected. Hence, no data from the accident flight were recovered. In another case, the tri-axis accelerometer was faulty, so no data were obtained for vertical acceleration, lateral acceleration, or longitudinal acceleration. Other parameters were being recorded properly, but this was an accident where longitudinal acceleration would have been very helpful in analyzing aircraft performance.

Both manufacturers have built-in failure-detection circuitry in their DFDRs, which causes an indicator to illuminate in the cockpit if current to the record head ceases, if tape motion stops, or if recorder power is interrupted. In consonance with Murphy's law ("if anything can go wrong, it will"), however, other failure modes have been known to befall the DFDR. For example, in one case involving an original-design DFDR, the tape motion continued, but was so erratic that no data could be read out. The flight data acquisition unit also has failure-detection circuitry, but this information is on the front panel of the acquisition unit and is not usually transmitted to the cockpit. The only foolproof way to detect a failure is to perform a short readout of each parameter as

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[24] *See* note 16 *supra.*

recorded during an actual flight at periodic intervals (as opposed to a readout of test data). Some airlines do this, but it is not a requirement.

The full value of the DFDR was evident during NTSB's investigation of the accident which involved an Iberia Air Lines DC-10 aircraft at Boston Logan International Airport in December 1973.[25] The flight recording system had been monitoring ninety-six different parameters. These data allowed the performance group not only to determine that the aircraft descended through a significant low-altitude wind shear, but to compute the winds which the aircraft encountered.[26] In the Iberia accident, a DFDR with mandatory and additional nonmandatory parameters (especially longitudinal acceleration, localizer and glideslope deviations, marker beacon signals, and autopilot mode selected) allowed NTSB investigators to prove—for the first time—that wind shear was a primary factor in an air-carrier accident. Without the DFDR, the accident might have been ascribed to "pilot error."

Since this time, a number of recent accidents have been attributed to wind shear.[27] As a result of these accidents, the FAA is sponsoring and encouraging rapid development of workable wind-shear detection systems for use at civil airports,[28] and the air carriers are putting more emphasis on pilots recognizing the effects of wind shear and on proper piloting techniques necessary to encounter such effects.

Federal Aviation Regulations now require fewer than twenty parameters on aircraft equipped with expanded parameter recording systems; in contrast, the Iberia DC-10 was recording ninety-six parameters on the same type DFDR used by all United States air-

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[25] Aircraft Accident Report, NTSB-AAR-74-14, Iberia Lineas Aereas de Espana [Iberian Airlines] at Logan International Airport, Boston, Mass. (Dec. 17, 1973) (available from NTIS).

[26] Address by W. G. Laynor and C. A. Roberts, A Wind Shear Accident as Evidenced by Information from the Digital Flight Data Recorder, at Proceedings of the 6th International Seminar, Society of Air Safety Investigators, in Ottawa, Canada (Oct. 1975).

[27] Aircraft Accident Report, NTSB-AAR-76-8, Eastern Air Lines, at JFK International Airport, Jamaica, N.Y. (June 24, 1975). Aircraft Accident Report, NTSB-AAR-76-14, Continental Air Lines at Stapleton International Airport, Denver, Colo. (Aug. 7, 1975) (both available from NTIS).

[28] Engineering and Development Program Plan—Wind Shear, FAA Report No. FAA-ED-15-2 (Mar. 1976) (available from NTIS).

lines which fly wide-bodied jets. The NTSB wants more parameters recorded on certain United States airplanes and has made such a recommendation to the FAA.[29] The FAA has issued a Notice of Proposed Rulemaking on the subject[30] and has solicited comments from interested parties. The proposed rules essentially call for newly manufactured aircraft, regardless of type, to be fitted with expanded parameter recording systems and to record all presently required and proposed parameters. In addition, the proposed rules call for all aircraft that are now required to carry expanded parameter recording systems to be retrofitted with the necessary transducers, sensors, and wiring to record the additional parameters.

Unfortunately, adding more transducers, sensors, and wiring to the aircraft now in service involves serious problems for the airline industry. It is expensive, and it takes a big airliner out of service for the retrofit period. The cost impact of such a retrofit program will probably cause its demise, although at the time of this writing, the FAA has not commented on the status of the proposed rules.

Perhaps the retrofit program is doomed, but what about the B-747's, DC-10's and L-1011's that are still on the assembly line? Could they be wired for more parameters? How about the older model aircraft that were certificated before September 30, 1969, but which are still coming off the assembly lines? Could they be equipped with digital recording systems instead of the oscillographic flight recorders? Regulations adopted after the issuance of an original aircraft-type certificate are not applied to that aircraft, even though many such aircraft have yet to be manufactured. Once an aircraft-type is certificated, it can be stretched and modified, but if it is operating under the original type certificate, the new rules do not apply. Hence, the new stretch DC-9 is rolling off the assembly lines with the oscillographic recorders installed rather than DFDRs—much less DFDRs with additional parameters.

DEFINITION OF A "LARGE" AIRCRAFT

A large aircraft is presently defined as an aircraft of more than 12,500 pounds maximum certificated takeoff weight.[31] However, a new definition is being considered:

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[29] NTSB Safety Recommendations A-74-15, A-74-16, A-74-17 (Mar. 1, 1974).

[30] 40 Fed. Reg. 23,058 (1975).

[31] 14 C.F.R. § 1.1 (1977).

> The use of the "12,500 pound" aircraft standard for purposes of operations under Parts 121 and 135 has been questioned and, based upon a preliminary review, the FAA believes that requiring an aircraft to be operated under the rules of Part 121 or 135 based on whether its maximum certificated takeoff weight is more or less than 12,500 pounds may no longer be appropriate or necessary in the interest of safety. Accordingly, the FAA has under consideration the development of new standards for operations conducted with large airplanes having a maximum passenger capacity of 30 seats or less, a maximum payload capacity of 7,500 pounds or less, and a maximum zero fuel weight of 35,000 pounds or less.[32]

Because the FAA does not wish to place an unnecessary economic burden on operators whose aircraft fall within the present and proposed definitions of "large," it issued a Special Federal Aviation Regulation (SFAR) on December 22, 1976, which states:

> 1. *Applicability*. Contrary provisions of Parts 121 and 135 of the Federal Aviation Regulations notwithstanding, large airplanes described in paragraph (a) of this regulation may be operated under Parts 121 and 135 of the Federal Aviation Regulations without a flight recorder or a cockpit voice recorder:
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> (a) Except as provided in paragraph (b) of this section, airplanes type certificated as large airplanes, having a maximum passenger capacity of 30 seats or less, a maximum payload capacity of 7,500 pounds or less, and a maximum zero fuel weight of 35,000 pounds or less.
>
> (b) This regulation does not apply to the following airplanes:
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> (1) Convair 240, 340, and 440; Martin 202 and 404; Fairchild F-27 and FH-227; Hawker Siddeley 748; and
>
> (2) Any airplane described in paragraph (a) of this section that on the effective date of this SFAR is listed on the operations specifications of a Part 121 or Part 135 certificate holder for operation as a large airplane and has an approved flight recorder, and cockpit voice recorder installed.[33]

The SFAR terminates on June 30, 1978, unless it is superseded or rescinded before that date.

Paragraph (b)(2) of the SFAR requires that recorders already in existence on certain aircraft be used and maintained. The FAA has issued an NPRM[34] proposing to delete this paragraph.

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[32] 41 Fed. Reg. 56,791 (1976).

[33] SFAR No. 33, 14 C.F.R. pt. 121 (1977).

[34] 41 Fed. Reg. 56,827 (1976).

FLIGHT RECORDERS ON CORPORATE JETS

In light of the SFAR of December 22, 1976, this writer doubts that the FAA will seriously consider at this time a recommendation by the NTSB that flight recorders be required on corporate jets. However, with present technology advancing at a rapid pace, the outlook for an inexpensive, lightweight, compact, and maintenance-free recording system is good. Various present and future systems are discussed later in this section.

As corporate flying becomes an ever-increasing part of the air transportation system, turbine-powered aircraft are doubling the travel radius of user companies. In addition, companies are discovering that they can save money by having their jets certificated under the air taxi provisions of the FAR part 135.[35] This allows them to lease the aircraft when not needed by the parent company. Gates Lear-jet has estimated that about one-quarter of its jets have been certificated under part 135.[36]

Since FAR part 135 previously required that operators of turbojet-powered airplanes with maximum certificated takeoff weights of over 12,500 pounds be equipped with voice and flight data recorders, a substantial number of corporate aircraft have been fitted already with flight recorders.

NTSB Chairman Webster Todd stated in a press conference on October 1, 1976, that he plans to ask the full Safety Board to make a recommendation to the FAA that would require voice and flight recorders on all corporate jets. Todd directed the on-scene investigation of the Johnson and Johnson Gulfstream-II crash at Hot Springs, Virginia, on September 26, 1976, where the three crew members and eight passengers were killed. The aircraft carried no recorders, and Todd concluded that this was a serious loss to the investigation.

Richard Aarons of *Business and Commercial Aviation* reports that:

> Aside from the probative value of CVRs and FDRs in accident investgations, there may be another benefit to be accrued from the installation of this equipment. Shortly after returning from the

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[35] 14 C.F.R. § 135.2 (1977).

[36] Bulban, *Billion-Dollar Year Expected in 1975*, AV. WEEK & SPACE TECH., Sept. 23, 1974, at 45.

> accident site, Todd told B/CA, "When the whole question of the corporate flight department's operations is on the line—as it always is after one of these accidents—knowledge of precisely what happened is terribly important. If you can't show that the accident was an act of God or some super-extraneous contributory cause, you can't beat the inherent fact that everybody who's negative on general aviation is simply going to say, 'Well, what do you expect?' "
>
> So it would seem, continued Todd, that it would be to everybody's advantage to get CVRs and FDRs aboard corporate turbojets.[37]

The question arises as to how much the recording system can be minimized in terms of costs, weight, size, and data storage capacity, and still be acceptable to both the NTSB and the FAA for use in corporate jets. Some work has already been done on developing and marketing a small digital recording system. Lockheed Aircraft Service Company of Ontario, California, and Plessey Avionics of England are jointly marketing a "minimal flight data recorder system" which combines the flight data acquisition unit with the DFDR in a single box. This is a modified ARINC-573 system designed to meet the FAR requirements for expanded parameter flight recorder systems and crash survival. The flight data acquisition unit is capable of encoding thirty discrete parameters and from twenty to forty continuously-varying parameters.[38] This system has recently been certificated in Great Britain and in the United States for use on the new two engine, thirty passenger Short SD 3-30 aircraft.

A very small digital crash recorder is being developed by Hamilton Standard of Windsor Locks, Connecticut, under contract with the United States Army. This system will use a microprocessor to decide which data should be stored and under what conditions and will use a nonvolatile solid-state memory instead of recording tape. Since a recording tape will not be used, the system will be virtually maintenance-free.[39] Projected costs are twenty-five percent lower

[37] Aarons, *Hardware/Software—"CVRs and FDRs,"* 39 Bus. & Com. Av., Nov., 1976, at 134.

[38] There are 80 analog wires. Some signal types use four wires for each parameter while others use two or three.

[39] The advantages of a solid-state recording medium over magnetic tape in an aircraft recorder include: (1) there are no tape transport mechanisms and other moving parts to jam or fail; (2) there are no magnetic heads to wear out or get

than ARINC 573 systems, with volume and weight over eighty percent less. This system will not meet the requirements of the Federal Aviation Regulations for twenty-five hour storage capacity, but it has exciting possibilities for use on corporate aircraft.

Storage capacity of Hamilton Standard's new recorder is limited to several thousand sixteen bit words, but the microprocessor allows "smart" recording. For example, instead of blindly recording a sample of each parameter at regular time intervals (as is done in the ARINC 573 system), an incremental value ΔP could be programmed for each parameter, so that a value of the parameter and the time of occurrence would be recorded only when the parameter value changed by $\pm\Delta P$. One could also program the unit to record local maxima and minima (and times of occurrence) of certain critical parameters, such as tri-axis accelerations, rather than waste memory space by recording at fixed intervals. Algorithms for the microprocessor are currently under study.

As for the CVR, at least one manufacturer (Fairchild Industrial Products of Long Island, New York) has available a modified unit costing about seventy percent of the standard CVR. It has only two channels instead of four and lacks some other features such as monitor-playback and bulk erase.[40] I know of no solid-state recording medium CR under development at this time. However, digital encoding of voice signals is possible and is in use today. For example, the "PULL UP" command on some of the ground proximity warning devices is digitally encoded. One problem with a digital CVR is that an extremely large amount of storage capacity is required for even a short, ten or twenty minute, period of recording time. The advantages are the same as for the solid-state DFDR, namely, it would be virtually maintenance-free.

CONCLUSION

The NTSB believes that recorders have contributed significantly to the present high level of safety enjoyed by the traveling public who use the air transportation system. Although having a flight recording system on board an aircraft does not prevent that par-

dirty; and (3) there is less susceptibility to vibration because there is no disruption at the contact between the tape and the tape head.

[40] *New Products and Services—"Fairchild's CVR,"* 34 BUS. & COM. AV., June, 1974, at 90.

ticular aircraft from having an accident, it can provide much information which leads to prevention of future accidents.

Wreckage in many cases no longer produces sufficient information to assess the causal factors of accidents involving today's complicated and fast aircraft. In addition, necessary data cannot be obtained by examining avionic circuits, such as are contained in automatic flight control systems and navigation receivers, once power has been removed. Hence, information recorded by the crash recording system has become of vital importance.