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Panel - Voice Recorder and Flight Recorder

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The comments made by the speakers are their own personal remarks and do not necessarily represent the official view of any organization or agency they represent.

MR. MARTIN RENGER: I am here as a manufacturer's representative, and probably and naturally talk from an entirely different angle than a lawyer would. But my job is to tell you what flight data recorders tell us. It is a great privilege to be here and to introduce you to one of the most valuable tools of aircraft investigation: the flight data recorder. Flying is by far the safest means of transportation and our commercial airlines have accumulated admirable records of safety and dependability; by comparison, driving a car almost seems like playing Russian Roulette. Nevertheless, accidents will happen. Since the early flying days, it has been the desire of the industry as well as the regulatory agencies to find out what really happens when such an accident occurs.

Before the advent of suitable recording devices, only a postmortem analysis of the wreckage and interviews of any available survivors or eight eye-witnesses could be used to search for the clues of such a tragedy. It is, therefore, only natural that ways were sought to record events leading to such accidents and to preserve such records for thorough analysis.

Flight data recorders have a long history with its origin going back to the early 1940s. Very early, the Civil Aeronautics Board, as it was called then, recognized the need for an effective tool to help in accident investigations. It seems no more than proper at this point to express our eternal gratitude to the late O. E. Patton of the Civil Aeronautics Board, which is now the National Transportation Safety Board, in this capacity. It was primarily through Mr. Patton's efforts and diligence that flight data recording has become as firmly established as it is now. I would also like to express my personal gratitude to Mr. Patton, whom I had the privilege to know and with whom we have cooperated for many years in the development of such suitable flight data recording equipment. It is, in fact, through Mr. Patton's writings that I have become initiated to flight data recorders, and Ed Patton's material has provided much background information for this introduction.

World War II prevented implementation of the first Civil Aeronautics Board regulation to carry flight recorders; this regulation, Amendment 100, as it was called, was to be effective by April, 1941. It required the installation of a device to record altitude and to record some indication of radio operation. Unfortunately, the war put an end to this and no such regulation was ever implemented. The end of the war brought with it a tremendous increase in aviation activities and naturally, the availability of such recording equipment now appeared more important than ever.

In 1947, the Civil Aeronautics Board again issued a regulation which required commercial aircraft of a weight of more than 10,000 pounds to carry equipment that was able to record altitude and vertical acceleration. Unfortunately, contemporary technology could not quite match this requirement and no devices became available that were able to demonstrate the necessary high reliability. Once more the Civil Aeronautics Board was forced to cancel its requirement.

Eleven years later, time was finally right for the first effective flight data recorder. In August, 1957, the Civil Aeronautics Board adopted amendments to the Civil Aeronautics Regulations (Parts 40, 41, 42 and 43) to be effective in September, 1957. These amendments required that as of July, 1958, flight data recorders must be installed in all aircraft over 12,500 pounds that are operated in air carrier service and above an altitude of 25,000 feet. The items to be recorded were air speed, altitude, heading (or direction), vertical acceleration and accurate time base. These recorders were designed to comply with the FAA technical standard or the C51 (later amended to C51A) which stated minimum performance characteristics and the number of design specifications including requirements for the survival of the recorder through adverse crash environments. At that time, values for an impact, shock resistance of 100Gs and a flame resistance for a minimum of 30 minutes of exposure to an aircraft fire, along with technical details with regard to size, shape, weight, electrical connections and so forth, were spelled out in an Airing Specification No. 542. At this point I should inject that Airing is an airline organization that specializes in developing equipment standards for the aviation industry. The government regulation permitted a choice between an injectable system, a system that extracts itself from the aircraft at the time of impact and thereby removes itself from the perils of exposure, or a survivable system, a system that is fully protected against such crash environment and stays with the aircraft. All manufacturers at that time decided to develop survivable units and to forego any ejection systems.

Now the investigators had a tool that was finally able to tell them what really happens to an airplane. Two basic types of recorders have evolved. One type was originally enclosed in a spherical enclosure and used a 2½ inch wide aluminum foil, while other systems designed to meet both the FAA and the Airing size and shape requirements used a high temperature resistant nickle alloy that was approximately 5 inches wide. Over the years, as the airplanes became heavier, faster and flew higher, additional demands were made on these systems with regard to performance, reliability and especially survivability. The FAA has issued a number of Air Worthiness Directives requiring users and manufacturers of such equipment to make additional provisions to safeguard against destruction of the recorder during the accident. Also, to further increase the survival chances of these devices, all flight recorders that had been installed in front or near the center of an aircraft had to be moved back to the tail section which was found to have the best chance of survival in most types of crashes.

A typical example of one of the early flight data recorders that was originally specified in 1958 is shown on the first slide. You may notice that its exterior is black and the compartment containing the magazine with the recording medium is covered by a transparent plexiglass door; the big black item is the recorder; the item in the upper left-hand corner is the magazine with the recording medium; down below you have the trip and date encoder, which allows the pilot to insert the date, flight number and so forth; and the little round object on the bottom is an accelerometer. As mentioned before, subsequent amendments to the basic regulation required the installation of additional crash protection; the recorder shell had to be painted a bright orange or yellow to facilitate retriveal of the recorder after the crash. The light plexiglass door was replaced by a heavy interlocking steel cover, the red item on the right side of the recorder, and additional armor plating was provided for the sides. Also, in some models, the cast frame enclosing the actual magazine was substantially increased in strength.

Contrary to the cockpit voice recorder, where the plastic magnetic tape requires elaborate fire protection, the flight data recorder medium exhibits a high built-in resistance against heat. Protection is therefore primarily aimed at the prevention of physical damage. Regulations require that recordings for an entire flight be preserved and that such records be maintained for at least 60 days. This is under normal operating conditions. Obviously if there is an incident, accident material is impounded and kept on file much longer.

The recording medium consists of a thin heart, 1/1000 of an inch thick metal foil, that is housed in a sturdy stainless steel magazine. Sufficient recording material is contained within one load to provide up to 800 hours of recording from a single spool of material. It may be interesting to note, the typical recording speed of such a device is exactly 6 inches per hour. Signals to be recorded are received from the aircraft systems in a number of different forms; air speed and altitude signals are generated emnemonically from differential pressures supplied by the aircraft static system. Sensors built into the recorder convert these special differentials into mechanical motion that is used to locate scribe arms and positions corresponding to the data value to be recorded.

For example, the altitude sensor moves the scribe arm into a position corresponding to the specific altitude indicated by the aircraft system or the aircraft itself. Then, motor driven cams depress the scribe arms at periodic intervals (approximately one second) into the recording medium, thereby engraving traces of these signals into the metal.

Direction, or magnetic heading as it is called, is taken from the aircraft compass system as an electrical signal. A device within the recorder converts this signal into mechanical motion and from there onto a scribe arm that is depressed by cams similar to the air speed and altitude cams.

Vertical acceleration signals, on the other hand, are generated by a separate accelerometer mounted in or near the aircraft's center of gravity. The electrical signals generated by this device are again converted into scribe arm motion. But in this case the scribe arm remains in contact with the recording medium at all times; it is depressed at a much more rapid rate by a special cam to provide a more frequent recording of this very rapidly reacting parameter.

Time is recorded either by inscribing timing marks generated by an accurate time source under the medium or, in the case of the Fairchild flight data recorder, by driving the recording medium at a highly accurate speed that by itself represents the time base of sufficient accuracy. Time in this case has been simply measured as a distance: 6 inches equalling exactly one hour.

Since we are dealing with a highly resistant and hard recording medium, diamond scribers are used to impress the information into material. This diagram represents a typical pattern of flight recorder traces. (It is essentially a replica of a piece of metal foil drafted for better contrast on a piece of paper.) Starting from the bottom, the first line or trace is the reference line that provides the basis for all read-out measurements. The scriber associated with this reference line is also used to inscribe specific coding signals such as the flight number, date, or any other pertinent aircraft information onto the medium. The next two lines represent altitude and air speed. In most flight data recorders currently in use, these signals are provided by mnemonic pressures. However, several carriers have elected to replace these mnemonic devices by followers that are located elsewhere in the aircraft. Using the central air data computer has resulted not only in a more accurate air speed and altitude trace, but also it has eliminated the need for long and troublesome mnemonic lines to the tail of the aircraft which have on occasion caused considerable installation and maintenance problems.

The next two traces indicate aircraft direction, or heading; the lower trace marked Heading Binary identifies whether the southern or northern half of the compass card is used, while the upper trace marked Heading Supplied is the actual direction. This parameter is recorded as a linear indication of heading by degrees. A heading of 0° is indicated when the scribe arm is in its normal or central position. For hearings in the east half of the compass card, the scribe arm records below the center position; it records above the center position for hearings in the west half of the card. The indications are the same for headings in the south half of the compass card, except in this case, the normal or center position indicates 180°.

Skipping one of the lines, we come to vertical acceleration. This scriber which is connected to a separate accelerometer mounted elsewhere in the aircraft gives a continuous or ten times per second record of the rapid vertical excursions of the aircraft as it travels through the air. Two more auxiliary scribers are provided to allow utilization of other aircraft devices. In some models one of these scribers is used to provide an accurate timing mark while in others, as in the Fairchild recorder, both of these auxiliary binaries, as they are called, can be used to correlate radio communications of the pilot and co-pilot with the flight data recorder trace and time base. These lines are shown just above the heading trace and at the upper edge of the medium.

How is data retrieved from this recorder? Usually, after removal of the recorder from the accident site, it is transferred to the National Transportation Safety Board (NTSB) in Washington. There the recording medium is removed from the recorder by skilled investigators and inserted into a special read-out device. As mentioned earlier, the distance of a scribe line from the basic reference line represents the specific value of the parameter to be investigated at a particular point in flight; this data combined with the accurate time base measurement of these distances enables the investigator to plot an accurate record of each of these parameters and thereby of the movement of the aircraft. Actual values for such measurements are provided by the manufacturers of these various devices in the form of calibration charts.

At this point I would like to enter a description of the highly sophisticated read-out device used by the National Transportation Safety Board. This machine is a high precision, measuring device which was designed and built especially to NTSB specifications for the read-out of such flight data recorders. A microscope is traversed across a fixed plot containing the recording medium in a site-to-site direction representing the X axis, or time parameter, and in a fore and aft longitudinal direction representing the Y axis parameter from the reference of base line trace; in other words, it records the actual excursion of the various scribe arms. Drives for each of the axis are electronically controlled and incorporated on digital indicators which simultaneously record any movement in either axis in increments of 5/10,000 of an inch from the starting point. These digital counters are resettable and include mathematical indicators so that excursions on either side of any initial settings are positively identified. The microscope is a binocular type with magnification capabilities of 100 times; it has an optical zoom feature which effectively doubles the maximum magnification. It incorporates both white and black field lighting systems; the insertion of colored or polarizing filters further helps in providing the maximum optimum illumination of these mental traces. The microscope also incorporates a means for attaching a special camera which enables a photograph to be made of any trace for study and further evaluation. The read-out machine further incorporates an automatic digital printer which expedites the transcribing of the raw X and Y data. The X and Y data is transferred onto automatic data processing equipment where the result and values are printed out.

Data is either numerically recorded or plotted as graphic pictures. Automatic plotting or graphs are transposed to an X and Y coordinate plotting machine and can be enlarged to almost any magniture. Although not every user possesses such elaborate read-out equipment, most operators have equipped themselves with sufficient read-out devices to perform calibration operations and to perform flight analysis and read-outs when special conditions warrant such actions.

Flight data recorders have been recovered from accident sites all over the world. Some have been excavated from impact craters. Some have been collected from thoroughly burned wreckage and some have even been recoverd by diving equipment in off-shore waters. In the overwhelming number of cases, read-out from these recorders has provided valuable information and has helped to pinpoint the cause of the accident. During the last few years the growing size and complexity of modern jet aircraft has shown a potential need for far more sophisticated recording requipments than are currently available. Highly sophisticated sensing equipment, high density digital recording techniques, and computerized data processing are now the topic of many regulatory proposals which in a few short years may drastically change the entire field of flight data recording.

NARRATOR: I do not think that it is an exageration to say that the flight data recorder represents one of the biggest milestones to unveiling the mysteries of air accidents. Still, it is a mechanical device and although it can retrace the movements of an aircraft with amazing accuracy, it tells nothing of the human element, the action of the crew and passengers during the fateful few minutes prior to such an occasion. It is not surprising, therefore, that very soon after the development of effective flight data recorders the need for such a voice recording device became most apparent.

In 1960 the Federal Aviation Agency, as it was then called, conducted a feasibility study on the possibility of recording spoken words of the flight crew during the flight of an aircraft. One of the greatest obstacles was the extremely high noise level in the cockpit. However, it was determined that recording of such conversation in the cockpit was entirely feasible. As a result, action was initiated for the development of such a cockpit voice recorder and industry participation was invited. From this study requirements were developed that ultimately led to amendments of the Federal Air Regulations, stating that cockpit voice recorders must be carried in essentially all transport category aircraft operated in the air carrier service. Effective dates for this mandate were established as July 1, 1966 for the turbine-powered aircraft and January 1, 1967 for all pressurized four-engine piston aircraft.

With some exceptions, these dates were met and all eligible aircraft are now fitted with such devices. These recorders, specified under an FAA Technical Standard Order, TSO C84, must be able to record each crew member's conversation with ground facilities and all conversations on the airplane's intercommunication system. Most important, direct conversations between crew members in the cockpit had to be recorded. The recorder must be able to retain the last thirty minutes of such conversations; it must also contain provisions to prevent accidental erasure of such recordings after a crash, and of course, it must survive the severe conditions encountered by modern jet aircraft.

Several companies participated in this program. I am very proud to say that Fairchild Industrial Products has assumed the leading role in this field, having supplied about 70% of all such devices currently in use.

What does a cockpit voice recorder look like? Its basic characteristics and minimum performance standards are again specified by the Federal Aviation Administration. These requirements are documented in a Technical Standard Order, TSO C84. As with the flight data recorder, size, shape, type of mounting, specific electrical characteristics, its color and many other details, are defined by an Airing Specification, Number 557.

The result of all this effort looks like this. A typical cockpit voice recorder system consists of two major units. As you can see from the slide, the recorder is the orange box, and the control unit is the little gray panel right next to it. The third item shows merely a variation of one of the control panels. The control unit containing the area microphone, pre-amplifier, erase and test switches, is located in the cockpit in the overhead between the two primary crew members; the recorder is safely installed in the tail of the aircraft.

As required in the regulatory specification, the unit is capable of recording on four separate channels for a duration of 30 minutes, with information stored longer than 30 minutes being automatically erased. In other words, the last 30 minutes of recorded information is always retained within the unit. This is accomplished by placing the recording on an endless re-cycling loop of tape, long enough to assure a minimum of 30 minutes per cycle. In our case, this amounts to approximately 300 feet of quarter-inch, standard, recording tape.

The four available recording channels are assigned to record all crew conversations within the cockpit and to record conversations of the first, second and third crew member with ground radio facilities or over the aircraft intercommunication system. In place of the third crew station the cabin attendants' microphone, which is connected to the public address system, can be assigned to one of the later channels.

Advances in microphone design, modern solid state techniques and clever application of recording techniques have made it possible to provide a highly intelligible recording of crew conversations in the cockpit in spite of the extremely high background noise levels. If you have ever tried to make conversation standing next to a jet aircraft ready to taxi away from the ramp, you will appreciate the magnitude of this achievement.

All this hard work would be wasted, of course, if the recording is destroyed in the crash. Much ingeunity went into the design of protective devices that safeguard the precious recording from the brutal exposure to heat, shock and crushing forces. The actual recording tape and its drive mechanism are encapsulated in a sturdy metal housing, sealed against dust and their undesirable elements. The most important part follows—the thermal enclosure. This element of the protective system insulates the recording tape against the extreme heat generated by a burning jet aircraft. A heavy stainless steel shell completes the protective encapsulation providing the necessary rigidity that will prevent the unit from being crushed by the forces of impact.

Here we have the principal components of the entire protective system. The innermost tape capsule is formed by the cover in the upper left and the drive mechanism, bottom third from the left. Fire protection is provided by the two white pieces in the center which, when assembled, enclose the entire tape capsule. The material contained in this assembly effectively prevents any damaging heat from reaching the magnetic tape. The armor-plated steel enclosure is formed by bolting together the two pieces shown in the lower left and the upper right corners. Completing the entire recorder is a bright orange, stainless steel cover on the extreme right.

It should be noted that while all certified systems in current use meet the basic regulatory requirements in this respect, some units, among them our recorder, have been designed to resist much more severe crash conditions, exceeding the minimum requirements of 100gs of impact and 30 minutes of fire. For instance, our recorder has been successfully tested not only to resist 100gs of impact, but also to resist double the required crushing forces and to resist exposure to jet fuel for more than a full hour. The wisdom of this extra margin of protection was quickly proven in the first major air disaster that took place after cockpit recorders had become mandated.

It may be interesting to mention that when our unit was originally tested to the 100g impact during our qualification program, virtually no deformation took place. By comparison this specific unit was deformed almost beyond recognition, indicating that forces have been encountered that were far in excess of any anticipated values. As a matter of record, the investigating team estimated that the unit was subjected to forces far above 100gs. Since that accident, there have been a number of accidents where voice recorders were subjected to heavy impact, fire of more than a hour, etc. In practically every case, units having that extra margin of safety survived satisfactorily.

How is the information retrieved or preserved from the cockpit voice recorder? First, the recorder must be found and painted a bright orange. Retrieval, on most cases, poses no specific problems. On occasion, divers and other underwater search gear have been employed.

Normally the recorder is forwarded to the National Transportation Safety Board (NTSB) in Washington. There, the type is removed from the unit and carefully played back on special reproduction equipment. To safeguard against possible loss of this valuable piece of evidence, certified copies are made of each recorder tract for further analysis. Skilled investigators analyze each recorder tract and prepare transcripts of all the recorded information. Very soon it was found that the term "cockpit voice recorder" should be correctly termed the "cockpit noise recorder." In a good number of cases the recorded noises, rather than the spoken word, have given more valuable clues and indications toward the cause of an accident.

With the sophisticated equipment available at the investigating laboratory, noise phenomena and specific frequency bands can either be isolated, enhanced or eliminated to reconstruct specific events in the cockpit. In this manner, it has been possible to determine engine speeds, the aircraft altitude and the function or non-function of various cockpit instruments and accessories helping pin-point the cause of trouble. Frequency spectrum analysis, voice print analysis, selector filtering and variable speed playback are only a few of the devices employed in such an investigation.

Obviously, such an inquisitive keeper of conversions and actions of an aircraft crew could be considered quite an intrusion into their privacy. In fact, much initial objection was encountered when the installation of such devices was first proposed. To safeguard against any misuse or abuse of such privileged information, regulations clearly specify that such recordings may not be used as evidence or basis for any punitive or disciplinary action against crew members. Also, bulk erase systems were installed in these cockpit voice recorders that permit air crews to erase all recorded information at the end of an uneventful flight.

From the beginning, equipment manufacturers have given substantial assistance in the development of read-out and analysis techniques and have participated heavily in the development of suitable equipment. Speaking for my colleagues in the industry, I feel safe to state that we always have made and always will make every effort to assist in obtaining the most complete read-out possible. However, it should be kept in mind that while we as manufacturers are more than willing to provide all the expert help that is required in such cases, we cannot furnish any interpretation of the record information.

Concluding my introduction to the cockpit voice recorder, I would like to salute our friends at the NTSB who have come to the conclusion that the cockpit voice recorder is by far the most conclusive and versatile tool of accident investigation that has so far been made available.

SPEAKER: MR. ROBERT SAWYER: Braniff has had flight recorders installed in their aircraft since receiving their first jets more than ten years ago. These instruments record the same parameters as those used today, namely air speed, altitude, aircraft heading and vertical accelerations. All are recorded against a time basis. In the early days of these recorders, their record was not very satisfactory. Mechanical difficulties in the recorder, maintenance errors and other problems produced a poor reliability. All to often when it was desirable to read the tape from the recorder, it was found that the tape was damaged, certain parameters were not recording properly, or the tape had been run too long and the record was a jumble of scratches upon scratches. Through the years the recorders and maintenance practices have gone through an evolution which has produced a recorder of acceptable reliability.

As a result of poor survivability in accidents and fires, the recorders have been moved to the tail of the aircraft where they are less vulnerable to crash damage and heat.

The read-out of these flight recorders is a slow and a tedious process. We own rather sophisticated equipment which includes a profile projector that reproduces the traces on a screen with high magnification. To accurately read a tape, however, takes almost as much time as it does for the aircraft to make the record. For this reason, all tapes are not read on a routine basis.

There are several conditions under which we do make a read-out of an individual tape. The most important, of course, is in the case of an accident or an incident where the information would be of value. Another case of importance to the airline is when there have been reported incidents of rough air or hard landing. When the pilot reports flight through rough air, the tape is immediately pulled and a measurement is made of the vertical acceleration experienced by the aircraft. The magnitude of these accelerations is then used to determine the extent of the rough air inspection that must be performed on the aircraft prior to its next flight. In most instances, the pilots over-estimate the severity of the turbulence, and only with the recorder do we have any quantitative means of determining what load experience the aircraft has actually encountered.

Sometimes during routine inspections we find damage to the aircraft structure which, due to the nature of the damage, could possibly be the result of high flight loads or a hard landing. In these cases, the flight recorder tape is examined for a series of past flights to see if some load condition might have been experienced but not recognized by the pilot.

In special cases, the recorder read-out is made to substantiate or refute reports of aircraft flight at an improper altitude or a flight on an improper flight path. In one very special incident we were asked by the FBI for assistance in determining what state an aircraft was over at the time a bomb threat occurred aboard the aircraft. The pilot was flying under instrument conditions and was unable with certainty to determine if he had crossed a state border prior to the occurrence of the incident. Apparently the verification of which state the aircraft was actually over was important in the prosecution of the suspect.

We sometimes do special monitoring exercises which require use of the flight recorder. A recent one was conducted whereby we monitored the approach flight path on all of our jet aircraft during a period of several months. This was done by placing an overlay on the screen of the profile projector on which we had inscribed lines which represented the steepest and the flatest approach flight path we considered acceptable for the particular type of aircraft. The approach flight path which exceeded these limits was brought to the attention of the chief pilot's office for further investigation. Special programs of this type also serve as a good monitor for the performance of the flight recorder in that it brings to light all recorder malfunctions or maintenance malpractices.

Braniff has had voice recorders in their aircraft since the year 1965. The voice recorder has 4 channels which record simultaneously. There is an area microphone in the cockpit which records all ambient sounds. It has channels for the pilot and the co-pilot audio selector boxes which record all radio transmissions or receptions from both positions. The fourth channel records the flight engineer's radio communication or the public address system, depending on the type of aircraft involved.

The early history of the voice recorder did not produce many mechanical or electrical problems but did provide some problems in the quality of the record produced. The area microphone which picks up all ambient noises was especially troublesome and required considerable experimentation in order to find a position with low enough ambient noise to permit interpretation of the cockpit voices.

The voice recorder is different than the flight recorder in its method of record retention. The flight recorder produces a record by scribing lines on an aluminum foil and this foil is removed from the aircraft and becomes a permanent record. The voice recorder, on the other hand, has a continuous tape which contains only 30 minutes of record because as the tape progresses through the recorder the old record is erased and a new record produced. Thus, only the 30 minutes of tape in the magazine contains the stored information. The aircraft system also contains a switch which permits the pilot to erase the record at the completion of a flight if no incident has occurred and no requirement for the record exists. The voice recorder, therefore, is not frequently read except for the purpose of maintenance checks and when incidents or accidents are involved.

The most important function, of course, for the flight and voice recorders is an accident investigation. The flight recorder records altitude, air speed, aircraft heading and vertical accelerations. These parameters are very helpful in determining the behavior of an aircraft prior to and during an accident. Prior to the days of flight recorders, most of the information about the behavior of the aircraft had to be gained from talking to eye witnesses, who often gave erroneous and conflicting information. For example, in a recent accident it was impossible to determine even the direction that the aircraft was flying prior to its breakup although many witnesses testified that they had observed the aircraft in flight prior to and during breakup. Only by the use of the flight recorder data was it possible to put together the aircraft flight path before and after structural failure.

As important as these recorded parameters are, it is seldom possible to determine an aircraft flight path by studying only the recorded read-out. The recorder can do no more than faithfully record what is reflected by the aircraft instrumentation. Airspeed and altitude can usually be taken at face value while the aircraft is intact and is flying in a normally reasonable altitude. High angles of side slip, line breakage and other abnormalities may cause the recorded information to differ from the actual changes in the air speed and altitude, however.

Heading information is probably the most seriously affected by aircraft maneuvers, and this information must be used with considerable caution when it is suspected that the aircraft may have been in some abnormal maneuver. Due to the mounting of the gyros in the compass system, a phenomena known as "Gimbal Error" may produce an error of the magnitude of 45° in recorded heading over that actually experienced by the aircraft. These Gimbal Errors may be of large magnitude any time the flight attitude of the aircraft exceeds 30° in pitch or about 45° in roll. It is also possible to reach the limit stops in the gyro system and cause the indicated heading to spin more than 360°. It is therefore difficult at times to visualize the aircraft flight path only from the study of the flight recorder information. But, the flight path may be of great significance, especially in an accident in which the in-flight breakup was present because it is usually very important to determine at what point in the flight path the structure failure actually occurred.

One question which must always be raised when looking at flight recorder data is whether a healthy aircraft could have produced such a record or was the record, in fact, made after major structure failure when the aircraft was experiencing an abnormal flight maneuver. In a recent accident, the flight recorder data was taken to a sophisticated, mathematical, computerized flight simulator. Early work on the simulator showed that the aircraft heading trace could not be produced by an intact aircraft. Additional work did show, however, that air speed, altitude and vertical acceleration traces could be closely duplicated if the aircraft were put in a high bank angle of more than 90°. The 90° plus bank angle immediately suggested large gimble errors of such a magnitude that it could explain the discrepant heading information. After many simulated flights it was concluded that a healthy airplane could experience a certain flight maneuver which was the terminal maneuver for the aircraft. During the course of the investigation of this accident, no other evidence was found which could have permitted a determination of the flight maneuver the aircraft had experienced, but the flight recorder data was able to do it only in conjunction with a flight simulator. Even though this was a daylight accident observed by several witnesses, the actual flight maneuver could not have been determined from their statements.

The voice recorder, when used in attempting to solve an accident, plays a complementary role to the flight recorder. Somewhat to our surprise, the intelligence gained from the voice recorder is different from and far broader in nature than expected. Cockpit convesations with evidence of calmness or anxiety are the things which we expected to learn from the voice recorder prior to its use in an actual investigation. All of us expected that cockpit conversation might be lacking or might contain only short phrases of profanity indicating flight crew discontent with the situation in which they found themselves. In fact, however, the voice recorder tells us much more. The voice recorder would be more correctly called the sound recorder, for it is the sounds other than voices which have been most significant in our experience in accident investigations. The sounds of warning horns and bells, the sounds of rain on the cockpit windows and roof, the sound of air going by the cockpit and the sounds of structural breakup have been most significant. These sounds are most meaningful when coordinated with the parameters recorded on the flight recorder. It has been our practice to plot the flight recorder parameters and the voice recorder sounds on a graph to the same time scale in order to get the most meaningful information from which to analyze the aircraft behavior prior to and during the accident. A very good time relation can be established on a real time basis gecause a voice recorder on the radio channel from the air traffic control center contains a time tick every five seconds which permits easy time correlation. We are now integrating these recorders by connecting the microphone circuits to the flight recorder in such a manner as to cause a trace to appear on the flight recorder tape each time the microphone is keyed in the aircraft. This provides an accurate method to take advantage of the air traffic control center time signals to establish real time for the flight recorders as well.

By use of both recorders simultaneously, it is possible to develop a much clearer picture of events prior to an accident. In one incident where the aircraft had gone off the end of the runway during landing, it was highly desirable to know the deceleration history of the aircraft. Flight recorder data during the landing role is not very satisfactory because reverse thrust interferes with the normal air speed system and air speed indicators read only down to an air speed of 60 knots. By the use of both recorders we are able to reconstruct the landing and the roll out. From the flight recorder data we were able to determine the touchdown speed of the aircraft but the rest of the intelligence required was gained from the voice recorder. We were able to determine exactly when, in real time, the aircraft touched the ground. We could hear the engines being put into reverse thrust position, and one of the crew members called out each thousand feet of runway remaining as the aircraft proceeded through its landing roll. By plotting these events against time, we were able to construct a dceleration graph for the landing run, and from this determine the effectiveness of the aircraft braking system.

Crew comments alone can be quite misleading unless the aircraft maneuver at the time of the comment is also known. Remarks made to cabin attendants or public address announcements to passengers can sometimes indicate what the flight crew intended to do. Conversation between flight crew members frequently indicates their awareness or unawareness of the development of a serious emergency. It frequently poses questions that require diligent search as to why the crew was not aware of the development of a situation, indicated by the flight recorder, that operative instruments and physical senses would normally have alerted them to.

In our work we have developed several special techniques in the use of the voice recorder. In one accident the flight recorder tape was damaged by the fire after impact and only part of the record was available for use in the investigation of the accident. The portion which was not available was the last portion of the tape and, of course, the most valuable to the investigation. In the section of the record that was available, however, the aircraft had attained a cruise speed of maximum allowable indicated air speed and it caused the air speed warning bell to ring. This bell, of course, was recorded on the voice recorder and gave us a point in time at which the two records could be correlated. It was determined that with appropriate filtering of the voice recorder, the ambient noise of the air flowing past the cockpit varied in intensity as the indicated air speed of the aircraft was increased or decreased. The portion of the flight in which both recorders were available showed this change in ambient air noise followed the aircraft air speed quite closely. With proper pen recording equipment we were able to produce a graph record of this ambient noise amplitude for the entire flight to the time of the accident. The sound record was then substituted for the airspeed of the aircraft in the portion of the flight for which no flight recorder data were usable. We have used this same technique in other instances. It has been valuable also where both records were recovered, in correlating the voice recorder and flight recorder, because plotting ambient air noise and the air speed to the same time scale permits laying the data from one recorder over the other so that all sounds on the voice recorder are in proper relation to the flight parameters from the flight recorder.

There is another phenomena associated with the voice recorder which we have discovered that has been quite helpful. This again involved an accident in which flight recorder data were not available. The voice recorder is mounted in the tail of the aircraft in a position such that the axis upon which the flywheel in the recorder rotates is parallel to the center line of the aircraft. If the aircraft is rolled abruptly to the right or to the left, the recorder frame is also rotated about this flywheel. When the aircraft rolls in the direction of the flywheel rotation, it has the effect of slowing down the flywheel in relation to the recorder frame. When the aircraft rolls in the direction opposite to the rotation of the fly wheel, it effectively increases the speed of the flywheel in relation to the recorder frame. In this accident, the 400 cycle generator frequency in the aircraft produced a hum in the voice recorder. Using this 400 cycle constant frequency as a base, we analyzed what happened to this recorded frequency during the aircraft maneuvers. It was learned that we had increases and decreases in the recorded frequency which was the result of the effective speed-up or slow-down of the flywheel in relation to the voice recorder frame. We then constructed a sort of see-saw and placed a voice recorder on it in the same relative position to the see-saw as it was to the roll axis of the airplane in flight. By moving this see-saw to represent different rates of roll, we were able to duplicate the voice recorder frequency shifts and thus determine the aircraft roll rates required to produce the same record. This information lead ultimately to our determination of what had caused the aircraft accident.

There have been other instances where it was possible to detect propeller overspeeds from the sound recorded on the recorder. It is also possible to get some measure of engine thrust by analyzing the frequency of the engine sound and correlating this with engine fan RPM.

Today's flight and voice recorders answer many of the questions that need to be answered in the investigation of an accident. Like many other devices, however, they also pose many more questions for which the answers are not available. We look forward to recorders which provide better serviceability so that their intelligence can more often be available after an accident. We also look forward to recorders with more parameters which will be able to provide more of the answers as to behavior of the aircraft prior to and during the accident. Once we have had the benefit of the data from these recorders, we realize how very difficult a task it is to determine the cause of an accident without them. This is especially true of accidents resulting from in-flight destruction of the aircraft. It has been our misfortune to participate in the investigation of five major accidents resulting from in-flight breakup involving our own aircraft and those of other carriers. Some of these accidents had the benefit of recorded data while others did not. In those in which we had the data, it has been possible to reconstruct the flight path and the aircraft behavior step by step from the position where the aircraft was in normal flight through the terminal maneuver. With the data available, we have been able to study the sequence of events with others and to arrive at agreement in at least that portion of the investigation. In those cases in which recorders were not available, several probable causes have been postulated and, without this kind of irrefutable data, it is doubtful that agreement on very many details of the flight will ever be obtained.