Air Safety Investigation in the Information Age

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Investigate, Communicate, Educate

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INTRODUCTION

Most of us have heard the belief expressed that we are living in the Information Age, due in large part to the proliferation of computers and the World Wide Web through which many of them are linked. As a result, the amount of information available in virtually all fields of endeavor has increased exponentially over the past two decades. This information continues to have the potential to increase with no end in sight.

As investigators we first learned to investigate by first gathering all the relevant facts, circumstances and physical evidence surrounding an accident or incident in a thorough, accurate and precise manner. In the past, the majority of the information gathered was based on physical evidence (wreckage) or circumstantial evidence (weather, witnesses, maintenance records). This information then formed the foundation and often, the limits of our investigation.

Under our traditional methods of collecting information on accidents and reported incidents we, as investigators, have to wait until an accident or incident has occurred and then wait for it to be *reported* before we initiate an investigation. At the same time, information surrounding hundreds of similar events remain unrecognized and unreported, the potential data remains uncollected and unscrutinized.

As the commercial airline fleet has evolved both in total numbers as well as in technical sophistication, we have found ourselves more and more often being unable to obtain key bits of transient information that are crucial to a complete and accurate determination of probable cause but have been lost in the aftermath of a crash.

According to the Federal Aviation Administration (FAA), after declining steadily since the 1950's, the worldwide commercial aviation fatality accident rate plateaued in the early 1980's. Given the projected increase in volume in international aviation traffic, studies by Boeing have forecast that unless the current accident rate resumes its decline, there will be a major hull loss every seven to ten days, somewhere in the world, by the year 2015. For the commercial aircraft industry this projection is unacceptable and even more importantly the flying public is not likely to accept an increase in occurrences of that magnitude.

We, as air safety professionals, have been challenged by aviation safety organizations to counter these rising numbers by reducing the current fatal accident rate over the next 10 years by at least 50%.

On reflection, the value of past investigative practices, while fundamentally sound, appear to have reached the point of diminishing returns in the face of evolving technological changes. Consequently, we are now faced with the task of raising air safety investigation to a level commensurate with the technology found in modern aircraft. In the future, we will no longer be able to wait for an event to be reported before taking action. Waiting will only compound the problem.

As we have learned over the years, accidents, incidents and other unreported events of a similar nature, have a rather unique numerical distribution. On *average,* as illustrated by the Heinrich pyramid, for every 1 to 3 fatal accidents there may be another 7 to 10 resulting in serious injury, another 30 with substantial damage, 600 with minor damage and *up to 1,000* more unreported events. The common thread that runs through these events are: their *random* chance of occurrence and the *similarity* of their underlying facts and circumstances. It is obvious then that the largest body of potentially *useful* information can be found within the base of the pyramid.

The stated goal of an investigation still remains to learn as much as possible about the factors that caused or contributed to an accident in order to prevent similar occurrences in the future. To make a significant difference in the future, we must focus much more investigative effort on those events that are currently unknown and/or unreported.

The most critical task in achieving investigative success in this segment hinges on the ability to collect useful information on heretofore-unreported events. Currently, the expansion of the information collection 'net' is providing investigators with a much wider and more detailed array of event information, encompassing virtually all phases of commercial operations.

As current technological advances have made traditional investigation techniques inadequate, those same technological advances have created opportunities for new techniques that will provide a greatly increased scope and accuracy in the collection of event information. In no area is this more evident than in the rapidly evolving onboard electronic systems. We are fast approaching the realm of the *virtual* accident in which events that were previously unknown will now be reviewed in a depth and detail not previously attainable.

The barriers to a successful investigation remains the same. The solution is access to *accurate*, *timely* and *complete* information across the broad spectrum of in-flight operations. The old nemesis from the past, '*limited time and resources*' will continue to attempt to restrict our efforts but this is also an opportunity in which we now have the ability to do *more* with *less*.

Accuracy of Information

First, to be useful, all event information should be accurate. This accuracy needs to be reliable and verifiable. It should be collected and handled in a way that minimizes the possibility of inadvertent loss or corruption of critical information. Subjective decisions and selective judgments can be made before an event in determining which information and sources are deemed applicable to this end such as trends, exceedances, fluctuations or any other anomaly that departs from the expected norm.

Completeness of Information

Second, for information to provide the 'big picture', more than the specific event needs to be captured. Additional parameters must be included and along a significantly greater timeline so that a more insightful history of the event can be shown. Completeness involves the collection of information over a series of cycles, encompassing a significant portion of the fleet for a given model. This will provide substantially more information than we had traditionally been able to obtain from flight data recorders (FDR) alone.

In the past, investigators have wished for access to information that was not being collected due to a limitation on the number of parameters. Digitalization has drastically changed that aspect, making collection of hundreds or even thousands of additional parameters an attainable reality.

Timeliness of Information

Third, the information should be timely. Unnecessary or avoidable delays in obtaining information can needlessly extend the period of risk. Real time access to information is critical in order to ensure that related information of a time-sensitive nature is also collected and preserved. We can no longer be totally dependent on the 'after the fact' reporting of an event by a flight crew or a mechanic in order to be brought into the investigative loop. Expanded electronic overall system monitoring will provide our first real-time information concerning a potentially hazardous result of a previously unknown event.

Development of Automated Information Collection

In the late 1950's, the increasing complexity of commercial airliners had already begun to overwhelm traditional investigation methods employed at the time. As the number of unresolved issues surrounding high visibility crashes began to multiply pressure from safety organizations mounted to find more reliable ways of collecting the information necessary to fill in those blanks. This led to the development of first commercial FDR in 1958 and later to the cockpit voice recorder (CVR). These additional requirements were initially resisted, however, based on additional cost, labor and potential loss of privacy.

Although, the first FDR's recorded only about six parameters, the early successes of FDR information providing critical information, along with continued advances in electronics, resulted in the number of recorded parameters to be steadily increased. Corresponding to these enhancements, the sophistication of sampling and recording the information occurred simultaneously. On this basis, the concept of the routine collection of what had previously been at best transient information began to be noticed by other areas of commercial aviation, most notably by maintenance.

The concept of having access to a wide range of flight information for every flight, every day, proved to be of great interest to operators and maintainers in terms of the potential for reduced operating and maintenance costs as well as limiting down time. From these initiatives grew formal programs such as the first FDR-based flight operation quality analysis (FOQA) program initiated by an European airline. The greater acceptance of flight data management (FDM) has led to several variants of the FOQA program, all providing access to an ever-expanding range of information.

Accessing Real Time In-Flight Information

To obtain and utilize this information for safety purposes, some FOQA programs currently incorporate a Quick Access Recorder (QAR) to download information from about 100 to 2,000 discrete parameters in modern aircraft. Once downloaded, this information can be readily analyzed and displayed by specially designed software programs.

By downloading every 3 to 20 days, depending on the type of analysis program employed, information related to a wide range of anomalies can be identified and analyzed in a contextual manner. Already, some aircraft communications and addressing system (ACARS)/Data Link systems now have an integrated airborne printer that allows flight crews to receive flight data information while still en route.

The QAR and the central maintenance computer (CMC), which also have the capability to capture data for analytical purposes, are now providing insights into flight operations and systems performance that had been previously unavailable. As benefits were gained through this new ability, operators soon realized the cost benefit effect on their bottom line, and they pressed to have the ability to monitor additional parameters.

Unlike the FDR, the QAR, operators have the advantage of being able to reconfigure the data frames to include or exclude specific parameters and/or increase or reduce the sampling rate. In addition, depending on the system architecture (an integrated QAR versus a stand alone version), the QAR can be linked with ACARS, providing operators the capability of a real-time data flow.

The impetus behind the development and utilization of the CMC is based on efforts to improve the dispatch rate and to provide a means to perform trouble shooting complex and integrated systems. The early versions of the CMC recorded only about 100 data messages. However, current CMC capability now affords the ability to record 7,000 messages in its non-volatile memory.

Within the CMC, the aircraft condition monitoring system (ACMS) has the ability to provide data through ACARS to a ground-based receiver. To add to its flexibility, the operator can reconfigure ACMS at any time. This allows the system the versatility to provide whatever data is needed at the time, without the need for system re-certification.

Although not part of the current automated QAR and CMC systems, the following components on many Embraer aircraft also contain potentially useful, retrievable component condition information as a function of their nonvolatile memory chips. These include:

- Ground Proximity Warning System
- Enhanced Ground Proximity Warning System
- Attitude and Heading Reference Unit (two per aircraft)
- Micro Air Data Computer (two per aircraft)
- Weather Radar
- Radio Management unit (two per aircraft)
- Integrated Navigation Radio (two per aircraft)
- Integrated Communications Radio (two per aircraft)
- TCAS Computer Unit
- Flight Management Computer (optional equipment)
- Display Unit (five per aircraft)
- Lighting Sensor Processor (optional equipment)
- Global Positioning Satellite System (optional equipment)
- Data Acquisition (two per aircraft)
- Integrated Avionics Computer

The Evolution of Automated Information Collection

The ACARS/Datalink was designed to provide a real-time method of transmitting information. The system provides great flexibility in that it can be userprogrammed to accomplish a variety of air/ground and ground/air data transmission reports. When this capability is combined with accelerated analysis and display programs, the time between information acquisition and the completion of formal analysis is significantly shortened.

The obvious benefit of incorporating an ACARS function with ACMS is that this combination allows engineering and maintenance personnel to have real-time knowledge of *current* in-flight problems. This in turn allows flight crews to receive a more in-depth and accurate insight into actual or potential system malfunctions, which can then identify the most viable options.

A final advantage of ground-linked data systems is that real-time transfers mitigate the vulnerability of the information hardware loss due to the result of impact forces.

Analysis and Use of Automated Information for Investigative Purposes

Once the data is collected and in order for it to have value, the information must be analyzed, and the results must clearly and completely be understood. Action(s) should be taken based on what has been discovered without any undue delay. The recent tragedy with the space shuttle Columbia highlights this fact beyond all doubt. There must be a clear realization among all involved as to the specific level of risk the recognition of an explicit hazard may present to the safe operation of an aircraft.

This ability to collect and analyze a large amount of information is also valuable from a variety of macro perspectives. Trends that were once indistinguishable with only the information available from a few events may now appear evident when viewed from the standpoint of the fleet. This is particularly important to smaller operators whose relative fleet density precludes in-house macro analysis. Consequently, the goal of information collection should be aimed at data sharing with all operators on a worldwide basis.

The result from this approach will not only identify potential hazards without the need of a reportable accident or incident but will also have the added benefit of identifying hazards in systems in which problems had not previously been suspected. Consequently, corrective actions can be based on faults that were identified through the analysis of the facts and circumstances surrounding *potential* accidents and incidents rather than requiring investigators to wait for an actual accident or serious incident to occur.

Current Data Link Restrictions

Information is transmitted by ACARS by means of a worldwide communications system operated by ARINC or SITA, which combines both satellite-based and ground-based VHF relay antennas.

Currently, the cost of using the system does not economically justify continuous flight data transmission. However, ACARS can be configured to automatically transmit abnormal condition reports for events such as in-flight shut downs, electrical malfunctions, and loss of pressurization or hydraulic power. Since these events are relatively infrequent, the transmission costs will not likely have a serious financial impact on the operator.

Of course, the main advantage of real-time information is the ability it provides operators in terms of strategic planning and fleet management. Current cost transmission levels, however, are not justified at this time in relation to the prospective cost reduction that could be obtained.

On-site Accident Information Collection

Regardless of how broadly and thoroughly we collect automated information, the importance of documenting on-site physical evidence should not be overlooked. The physical evidence will become even more relevant since it is now possible to compare and correlate that evidence with a much wider range of electronic information than had been available in the past. Here too, though, there are new tools currently available to improve the speed and accuracy of on-site documentation.

In debris fields, in which the terrain is expansive or difficult to transverse, hand-held, global positioning units can establish the location of critical points in a wreckage distribution that are now accurate to within a few feet.

Optical or laser range finders allow investigators to more accurately measure moderate distances over what might be inaccessible terrain.

Metal detectors help detect buried components that might otherwise not be located during an onsite investigation.

Many investigators now routinely use video recorders to add in the post-crash documentation process. The photographic quality and low light capabilities of these recorders adds another dimension to wreckage documentation. Video recorders with 5 or more mega pixels are also a source of additional photographs that retain excellent resolution in up to 8X10 enlargements.

However, the most dramatic advance is in the area of wreckage description, which involves laser scanning and digitizing an entire crash site. This provides the investigator with a perfectly scaled, three dimensional depiction of any wreckage distribution with the ability to rotate, zoom in and out, while seamlessly providing the ability to move from point to point thus viewing the wreckage from virtually any perspective with photographic resolution. Measurements between any points obtained through this process have been shown to be accurate up to 1/8 inch. The equipment, while still bulky, is portable and the scanning speed is increasing at the same rate that computer processor capability is increasing. With this aid, an investigator will be able to '*revisit*' any aspect of the accident site, obtaining additional details, measurements or photographs at any time and from any position just by opening a computer file.

Follow up Information Collection

If a suspected component has been identified and located, routinely, a photographer will be present to pictorially record the 'before' and 'after' of each step of the inspection process. An overall digital video recording of the event, while not intended to replace photographs, will add a dimension of context and continuity to the entire process, while also enabling the investigator to simultaneously add a narrative description. As we have learned with witness interviewing, a much more detailed description will result from an oral narrative as opposed to written statement.

Follow up Research and Analysis Information

If a component shop finding does not satisfactorily disclose the precipitating cause of the discrepancy, a more scientific examination, such as a metallurgical examination, may be warranted but the detail precludes the use of a hand-held camera or video recorder. Many times a scanning electron microscope (SEM) is frequently employed to examine suspect surfaces on an extreme microscopic level. Most SEM's have the ability to have their findings downloaded directly to a personal computer (PC) so that cathode ray tube (CRT) images and spectrographic material analysis plots can be directly saved for storage and later reference.

Displays of Circumstantial Information

From an investigative perspective, real time reenactments and animation allow investigators the added insight sometimes needed to more fully appreciate the interaction of crucial factors from a simulated real world perspective. The added dimensions of an aircraft in-flight, control movements, instrument displays, and environmental factors combined with the added dimensions of sound, and time, now allow investigators to obtain a contextual sense of what the pilot and the aircraft were experiencing as the event progressed.

During collecting flight data and FDR information collection, advances in computer simulation and full-motion simulators can be combined with radar data, weather satellite imagery, terrain mapping, and air-ground communication information. In addition, the ever more sophisticated software programs now provide the ability to replay the data. This real time format allows the investigator to access real time audio, topographical views, weather restrictions, aircraft movement and systems performance, in an animated format or to review the event in a flight simulator.

When radar data is combined with information from the FDR and is displayed in conjunction with a topographical database, programs can accurately depict a recreation of the aircraft in flight. The viewer's point of reference can be shifted to various vantage points, inside and outside the aircraft, while concurrently displaying real time flight instrument readings and flight control movements.

Recordings from air traffic control (ATC) and CVR audio often contain information beyond the value of mere words. A greater insight into procedures, crew resource management (CRM), and cockpit sounds can have added significance when put into context with simultaneously occurring events.

For several years, proposals have been made for the inclusion of a cockpit video recorder. It is unfortunate but with the occurrence of 9/11, and the changes in security that have been implemented, the advent of on-board cockpit video recorders may yet come to pass. With the advances in recording digital images, this may allow us the see *what the pilot saw and did* correlated with *what the pilot heard or said*.

Flight simulators can present a degree of realism that from a pilot's standpoint is evermore approaching the reality of an actual aircraft. The expanded capabilities of today's simulators allow the programming of accident data so as to recreate an accident or incident based on the electronic information obtained from the FDR and/or FOQA while utilizing ATC and CVR audio as an additional reference. The visual displays can incorporate the actual runway in use for takeoff or landing events.

Organizational Information Collection

All the advances in information collection have not been limited to automation. The approach to human factors has also evolved significantly during the past 30 years. Advances in theories of accident causation were also occurring and providing insights into the roles that organizational management play in an accident scenario. We have made significant reductions in environment and hardware related events but in the area of human factors and the expanded area of human factors in the organization there is still significantly more that can and should be accomplished.

The Reason Model of accident causation that is now most prevalently used by air safety managers has significantly expanded the view of accident causation bringing us into the age of the *organizational* accident. This is significant because the model identifies not only proximate factors and active failures but also allows us to identify latent failures introduced into the system as a *result* of faulty or inadequate organizational processes as well. While faulty or inadequate organizational processes do not directly cause accidents, they do, however, significantly increase the *probability* of an accident by introducing unrecognized latent failures.

In the past, the collection of organizational information has been one of the less undeveloped areas of an investigation for several reasons. First, the organization often seems quite far removed from the actual event and senior management is often immersed in an agenda that views a wide variety of processes from a macro perspective. Second, the information is often difficult to access objectively since reliable and valid methods for collection and analysis of this information were often not available. Often times the investigator receives scant encouragement or support even from his organization.

Until relatively recently, it has been difficult to quantify organizational information with any degree of validity and reliability. Researchers realized that in spite of the difficulty in collecting and analyzing organizational information, the difficulties did not preclude its importance in fully understanding what caused and *contributed* to the event.

In a successful investigation, after identifying the proximate events in the accident sequence, the next question is likely to be "Why did this happen?" or "Who or what allowed or caused this to happen?" Virtually every aspect of any accident can eventually be traced back to an error, omission or violation committed by someone far removed in place and time from the final event.

Given that any organization is designed and operated by people, it follows then that human factor problems also exist in an organizational or management process. By examining the concepts and models of contemporary safety researchers in accident causation and organizational error, it has now been shown, through human based research, that it is possible to arrive at a quantitatively based conclusion regarding the role the organization played in the overall accident sequence.

The researchers (J. Reason, J. Rasmussen, D. Maurino, J. Williams) and others have all contributed to the continuing refinement of the accident causation model. With that development has come the ability for investigators to identify and quantify the faulty or inadequate organizational processes that worked to defeat defensive safeguards and increase the probability of the occurrence of an unplanned, adverse event. Some training and practice is required since many investigators have not yet been sufficiently exposed to this process.

The importance of conducting a thorough organizational investigation cannot be over emphasized due to the negative and pervasive effects of organizational errors have on a safety culture. While these errors do not directly result in accidents or incidents, they do, however, result in *conditions* that are conducive to the creation of latent errors that can be identified as cause factors.

Potential Loss of Information Collection Opportunities

Chronic problems still remain in the area of information collection. The loss of potentially useful information may result from delays or inaction during the investigative process in the same way that shortcuts or abbreviated procedures can also impair an investigation. Consequently, it is important for an investigator to know both the sources of information as well as the windows of opportunity for the collection perishable information.

With these two factors, for example, the investigator for a manufacturer may be concerned with obtaining a part that had been removed before the operator discards or submits the part for overhaul. The inability to acquire an unserviceable part may impair or setback the investigative process, sometimes requiring the investigator to wait for a comparable event to occur in the future in order to make further progress.

Similar problems with lost information can occur when troubleshooting intermittent faults is not properly performed and parts are replaced based on the recollection of what seemed to have corrected a similar problem in the past. In this instance, the ‘remove and replace’ approach to troubleshooting may result in the removal of a part that had nothing to do with the problem. Since the fault is intermittent, a satisfactory operational check may not reveal the uncorrected problem. Consequently, an examination of the part will be productive only in terms of ruling it out as causing or contributing to the problem.

Delays in obtaining FDR information for past events, which have significance to the manufacturer but have not raised the same degree of interest with the operator, are common sources of lost information.

The collection of CVR information has a much more limited retrieval window. The looped CVR information is subject to inadvertent loss through a failure to power down the recorder after an event has occurred. This results in an information loss as the CVR records over and thus erases the desired information.

The physical distance from the maintenance facility, which prevents the investigator from establishing a professional working relationship with the operator through frequent visits, reduces the investigator to a voice on the phone or a name on a business card. This lack of a personal relationship may result in a potentially serious problem remaining unknown or unresolved by the manufacturer for an extended period of time. Lost or delayed information retrieval resulting from poor communications allows the opportunity for the same event to reoccur.

Thank you for your attention. Are there any questions?