2009

Constructing Accurate and Precise Timelines for Major Aviation Accident Investigations

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A clear, precise, and accepted description of what happened in an accident is a necessary first step in understanding why an accident happened. Although timelines are routinely used in accident investigations, constructing an accurate and precise one can be difficult. Large volumes of information must be correlated to a common time base, and the significance of events can change as the investigation develops. This paper describes the development of a timeline application to help overcome the difficulties associated with accident timelines. Development has emphasized interactive capabilities that allow users to manage the content and format how evidence related to the accident sequence is presented. The paper concludes with a discussion about how accident timelines can enhance communication and information access.

Timelines are routinely used in accident investigations to establish *what* happened in the accident, a necessary first step in determining *why* the accident happened. Their value lies in the identification of critical events, issues, and relevant evidence, especially in the early stages of the investigation. As the investigation develops and additional information is uncovered, more detail about the events and underlying conditions can be included on the timeline.

In addition, a timeline can be used to show the juxtaposition of events and underlying conditions that explain what happened in the accident. Recognizing the relevant relationships from events and information may point to causal and contributing factors and shape the direction of the investigation. In this way, accident timelines help bridge the gap between what happened in an accident and why it happened.

Despite such added value, constructing an accurate and precise depiction of critical events in a major aviation accident can be difficult. Investigators must correlate large volumes of information from numerous sources to a common time base, and the significance of particular events often changes as the investigation develops and new information becomes available. As a result, the selection of critical events from the complete set of available information and a meaningful presentation of those events can be a challenge. To overcome these challenges, the National Transportation Safety Board (NTSB) developed the Accident Critical Events Sequence (ACES) timeline application as a user-centered timeline application to support major aviation accident investigations.

The purpose of this paper is to describe the development and implementation of ACES, and show how it displays the sequence of events leading to an accident and gives investigators rapid access to related information. The paper begins by pointing to aspects of investigative activity that make constructing the sequence of events leading to an accident difficult. The discussion then turns to the motivation to develop ACES to overcome these challenges. The paper concludes with a discussion of effective areas of ACES implementation in ongoing investigations.

ACES is being developed as part of a larger NTSB effort to evaluate ways to improve the management of a major accident investigation. The Principal Issues Management Model (PIMM) being used by the NTSB focuses on managing principal issues, which are defined as significant aspects of an accident that directly relate to the factors underlying events and actions that occurred (Coury, et. al., 2008). Briefly, principal issues comprise the hypotheses or questions that the investigation must answer. Principal issues arise as the investigation progresses, and may require intensive efforts by multiple, interdependent investigative groups to gather evidence to answer questions raised by these issues. Because many of the questions associated with principal issues concern the chronological sequence of accident events, an accident timeline is essential. ACES is being developed to display critical events and related information, to provide a way to manage information from specific investigative tasks, and to communicate important time-related information to the entire investigative team.

The initial development of ACES drew upon other efforts to develop accident timelines. For instance, Events and Causal Factors Charting is employed by the United States Department of Energy to represent the multiple events and underlying conditions that contribute to the occurrence of an accident (DOE, 1999). The Transportation Safety Board of Canada uses a similar method—a Sequence of Events and Underlying Factors Diagram—to document the sequence of events leading to an accident (Ayeko, 2002). Finally, Sequential Timed Events Plotting (STEP) is an investigative methodology based on a multi-linear display that shows how events interact to produce an accident (Hendrick and Benner, 1987). Although ACES has some of the same characteristics as these other types of timelines, it is unique in its ability to depict, integrate, and display events and time-related data from multiple sources. The specific investigative challenges considered during the development of ACES are discussed in the next section.

ACES

NTSB has developed the ACES timeline application to help investigators depict and describe the sequence of events leading to an accident. Currently, ACES is a prototype built on Microsoft Excel 2003. Early development centered on establishing the functional requirements of the application based on the needs of the individual investigator and the investigative team. Updates and modifications to ACES relied on data collected through interviews with NTSB investigators, through usability testing, and through the observation of ongoing investigations to identify the specific investigative challenges that ACES should address, as described below.

First, NTSB investigators spend a significant amount of time and energy identifying what happened in an accident. This understanding forms the basis for determining the causal and contributing factors that explain why the accident happened and the actions necessary to prevent its recurrence. However, the management and analysis of information available to reach these conclusions can be overwhelming and presenting it in a way that is digestible can be difficult.

Second, because accurate and reliable timing is fundamental to a useful depiction of the sequence of events in an accident, careful correlation of all of the times used for data derived from event recorders [for example, the cockpit voice recorder (CVR) and flight data recorder (FDR)] is necessary. This correlation requires specialized knowledge and understanding of the timing involved in relevant systems.

Third, NTSB investigators focus on collecting evidence related to their fields of expertise, and there is a need for a centralized repository where diverse event-related evidence from each of the investigative groups can be displayed. Such an integrated depiction would help investigators identify issues requiring further investigation and help establish the relationship of events from different functional areas. In addition, the precision and relevance of time-stamped data can change over the course of the investigation, and these changes must be verified and communicated to the entire investigative team to ensure a shared understanding of accident events.

To overcome these challenges, ACES development has emphasized interactive capabilities that allow users to easily add, remove, and modify information to generate timelines that meet both individual and group needs:

- Users can customize how much detail is presented.
- Presentation options allow users to view events from different information sources that overlap, interact, or occur at the same time.
- Events and parameter data are color-coded so that different types of information can be easily distinguished from each other.
- External files from documents, pictures, and records can be linked to timeline events to provide access to more detail without cluttering the display.
- Finally, the synchronization of different time sources can be easily defined and updated.

The ways in which ACES manages the content and format of information presented to the user is expected to help overcome the challenges to constructing accident timelines and provide a mechanism to enhance communication and information access among interdependent investigative groups. ACES is also a repository where diverse, event-related evidence can be displayed in one place. The section below describes how accident data are used to generate an accident timeline on the ACES Graphical Display.

ACES Graphical Display

ACES works with text-based event data and numeric parameter data. Users enter these data types on individual worksheets within an Excel workbook that have been designated for that information source. Ultimately, these data are integrated into the accident timeline on the ACES Graphical Display as vertical text boxes and time-history plots, respectively. An example of the ACES Graphical Display is presented in Figure 1.

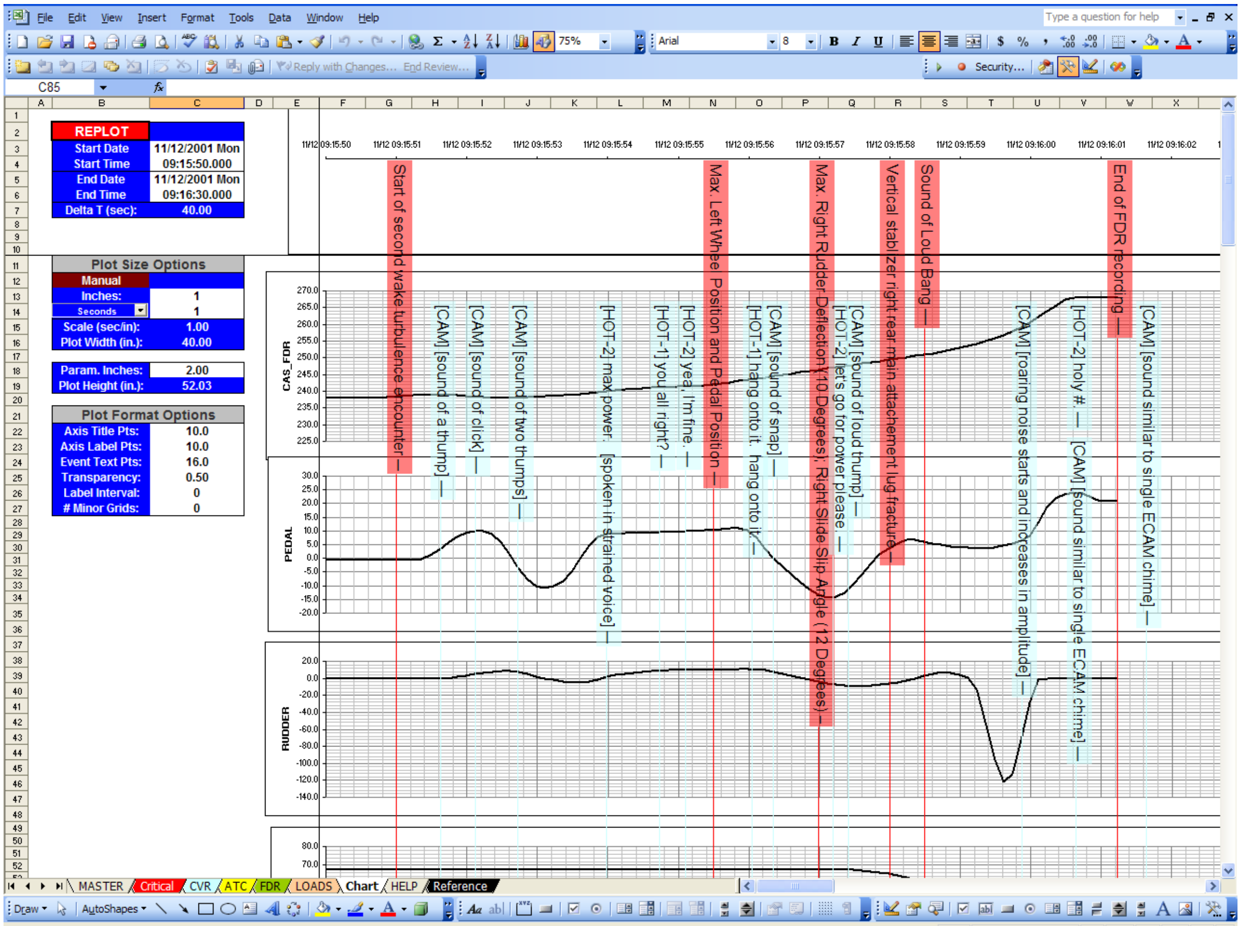

Figure 1. Example of ACES Graphical Display illustrating events from the NTSB investigation of American Airlines Flight 587 (NTSB, 2004).

The horizontal axis represents the master time for the investigation. Time runs from left to right and text-based events are printed vertically underneath the times when they occurred. Optional time-history plots of parameter data appear on the vertical axis and are intersected by lines dropping from the times corresponding to the text-based events. To the left of the timeline is the user interface, where investigators can manipulate the displayed time range, the scale of the horizontal axis relative to physical screen space, and other display settings. Finally, the sheet tabs located at the bottom of the screen allow users to navigate between each information source, a master sheet that amalgamates all of this information in a tabular format, and the ACES Graphical Display.

The information used to generate the accident timeline presented above was derived from the air traffic control (ATC) transcript, CVR, and FDR and was correlated to a common time-base. Additional information from weather reporting facilities, pre-flight maintenance logs, dispatch logs from emergency responders, training records, witness interviews, etc., can be incorporated on the accident timeline as well. ACES' ability to manage this diverse event-related evidence is described below.

Effective Areas

The evaluation of ACES during several ongoing aviation accident investigations indicates it is an effective investigative resource. ACES has been found to be most useful in three areas:

1. Documentation and illustration of *what* happened in an accident
2. Support of collaborative investigative decision-making and problem-solving
3. Resolution of time discrepancies from multiple time-stamped data sources

The first area is critical for any accident investigation. A clear, accurate, and accepted description of *what* happened in an accident is a necessary first step in understanding *why* the accident happened. For example, the identification of an event may prompt accident investigators to recognize the relationships among other events in the accident sequence, support conclusions made about other issues, or ask new questions that otherwise may have been delayed or overlooked. ACES effectively documents, catalogs, and illustrates what happened in an accident.

The second area results from the complexity of an accident investigation and the need for input from many individuals, representing different areas of expertise, to find solutions to problems and make sound decisions. For instance, determining the configuration of an aircraft during landing may require evidence from the Operations Group to determine if the aircrew configured the airplane properly, evidence from the Vehicle Performance Group to determine the airplane's behavior, and evidence from the Human Performance Group to determine the effect of task complexity on crew resource management. This example highlights the interdependencies between investigative groups and underscores the importance of providing investigators with rapid access to evidence related to critical events at any point in the investigative process. ACES provides the capability for diverse event-related evidence to be displayed in one place and manipulated so that investigators can see the relevant relationships.

The third area relates to the synchronization of time-stamped data sources. The time bases underlying information from event recorders, radar data, witness statements, and other sources of time-related data are generally not synchronized and can vary in accuracy. However, building a precise depiction about what happened in an accident depends on the accurate placement of events in relation to one another. Consequently, synchronizing time-stamped data from multiple sources is of paramount importance. An accident timeline provides a mechanism for merging all the "clocks" from different information sources and synchronizing them to a master time. ACES performs this synchronization and presents an integrated timeline of events referenced to a common master time.

It is also worth mentioning that the initial development and implementation of ACES assumed that the application would be centrally managed by a single individual, with investigators working with that person to obtain necessary data plots and timelines. Development of ACES has changed course as a result of the ongoing evaluation to move the application in the direction of a stand-alone tool that can be used by investigators to create their own data plots and timelines. For instance, a user's manual and training modules were developed to accompany and provide guidance in the use of the application.

Conclusion

ACES was developed to help organize, present, and communicate factual information relating to the accident sequence to the entire investigative team. ACES clearly conveys the sequence of events leading to an accident and enables investigators to customize the content and format of information to meet both individual and group needs. Currently, ACES allows users to select subsets of accident data and synchronize time-stamped data from different information sources.

ACES is a new approach for constructing accident timelines and its potential to support investigative activity as part of PIMM will continue to be evaluated. This paper has addressed specific investigative needs that must be considered when constructing an accident timeline and discussed the ways in which ACES has demonstrated its value as an investigative resource. Future research is planned to determine the steps necessary to fully integrate ACES into the accident investigation process.

Acknowledgements

The views expressed in this paper are not those of the National Transportation Safety Board and are solely the views of the authors.

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