

From Flight Logs to Scenarios: Flying Simulated Mishaps

Webb Stacy, Ph.D., Paul Picciano, Ph.D., Kevin Sullivan, M.S., Jason Sidman, Ph.D.

Aptima, Inc.

Woburn, MA

wstacy@aptima.com, ppicciano@aptima.com, ksullivan@aptima.com, jsidman@aptima.com

ABSTRACT

Flight safety is an important aspect of any pilot training curriculum, and there is no better material than accounts of actual incidents. Precise data are often available from Flight Data Recorders (FDRs), and the Military Flight Operations Quality Assurance (MFOQA) program finds rich, meaningful high-level events in those data. Unfortunately, with current technology such flight data and events can only be replayed; pilots cannot actively re-fly the mishap unless someone has manually (and laboriously) recreated a scenario from it. There is value in the replay, but immersing the pilot as an active participant in a scenario that requires decisions and actions at critical points makes the training more relevant, memorable, and effective.

We are working to speed the process of creating scenarios from flight logs with a four-step process: 1) the original flight path is provided from FDR data and MFOQA events, either from the actual aircraft or from a re-creation in a simulator; 2) on the flight path, the scenario author identifies key events and pilot decision points; 3) the scenario author generalizes the events and decision points into “regions.” The generalization step is an acknowledgement that a safety incident will never happen exactly the same way twice—the location, altitude, speed, or other aspects of the situation may be different from the original mishap; and 4) the author connects those regions into a continuous envelope. This constitutes the scenario. As long as pilots stay within this envelope during the simulator mission, they will encounter the circumstances involved in the mishap, and they will arrive at the mishap’s critical decision points.

In this paper we will discuss the automated support necessary to accelerate the creation, and enable the monitoring, of mishap-based scenarios, and will give working examples of their application and benefits.

ABOUT THE AUTHORS

Webb Stacy is Vice President of Technology and Aptima Fellow at Aptima. Dr. Stacy oversees Aptima’s current and future technology portfolios. His focus is the intersection of software and computer science with the science, modeling, and measurement of training warfighters as individuals and as teams. He holds a Ph.D. in Cognitive Science from the University of Buffalo and a B.A. in Psychology from the University of Michigan.

Paul Picciano is a Sr. Human-Systems Engineer with more than 10 years experience solving problems for the human operator. Dr. Picciano has worked in aviation human factors for much of his career, investigating issues on the flight deck, air traffic control, and their interaction. Dr. Picciano earned a Ph.D. in Cognitive and Neural Science from the University of Utah, a M.S. in Human Factors and Ergonomics from San Jose State University, and a B.S. in Mechanical Engineering from Tufts University.

Kevin Sullivan is Senior Director of Software Engineering at Aptima, Inc. Since joining Aptima in 2006, Mr. Sullivan has directed Aptima’s Software Engineering Division, and has been responsible for creating Aptima’s product lines and managing multiple DoD software engineering efforts in the intelligence, and aerospace fields. Mr. Sullivan holds a M.S. in Computer Science from Boston University and a B.S. in Science and Humanities from the Massachusetts Institute of Technology.

Jason Sidman is a Senior Scientist and the Leader of the Multimedia and Instructional Design Team at Aptima. Dr. Sidman’s research interests are in training needs analysis, training design and distributed learning. Dr. Sidman has served as both Principal Investigator and Project Manager on distributed learning development and evaluation projects. Dr. Sidman received a Ph.D. and M.S. in Experimental Psychology from Tufts University, and a B.A. in Psychology from the University of Massachusetts, Amherst.

NAVAIR Public Release 10-1026

Distribution: Statement A- "Approved for public release; distribution is unlimited"

From Flight Logs to Scenarios: Flying Simulated Mishaps

Webb Stacy, Ph.D., Paul Picciano, Ph.D., Kevin Sullivan, M.S., Jason Sidman, Ph.D.

Aptima, Inc.

Woburn, MA

wstacy@aptima.com, ppicciano@aptima.com, ksullivan@aptima.com, jsidman@aptima.com



Flight safety is an important aspect of any pilot training curriculum, and experiential training in an interactive environment such as a simulator—that is, active learning—is an essential part of a good flight safety training program. This paper is about new ways to create scenarios for that experiential component that both engage trainees and broaden their exposure to potential safety concerns.

Because severe mishaps are of great importance to the military aviation community, pilots tend to be familiar with the details of actual mishaps. They often even know the personnel involved. This means that scenarios that are accurate and contextually valid recreations of the mishaps are an excellent way to maintain both trainee engagement and trainee motivation.

On the other hand, those mishaps will never recur in exactly the same form. The location, altitude, heading, equipment status, weather, terrain, or a host of other factors might be different. Thus, for best preventative effect, the experiential component of the training program will need to include scenarios with the same underlying cause but whose circumstances are quite different.

Unfortunately, there are difficulties in creating both kinds of scenarios. For mishap recreations, precise data about the flight are often not available. Instructors are often required to guess at initial conditions and in-session events. For the scenarios involving experiential variation, instructors must creatively yet consistently and accurately imagine other relevant scenarios. As intelligent and creative as instructors are, this is a lot to ask.

A potential solution is to leverage a program called Military Flight Operations Quality Assurance (MFOQA). In this program, the Department of Defense is leveraging lessons learned from the commercial airline industry and exploring ways to use precise data about flights as the basis for training—as well as

maintenance, operations, and safety. In particular, precise flight data about the mishaps will be increasingly available, and this will provide a leverage point for experiential safety training.

Doing so will require a new approach, however. With current technology such flight data can only be replayed. Because the flight data specifies every detail at every moment, pilots cannot influence the flight and therefore cannot actively re-fly the mishap. There is value in the replay, but immersing the pilot as an active participant in a scenario that requires decisions and actions at critical points makes the training more relevant, memorable, and effective.

We are working to enhance the process of creating such scenarios from precise flight data. The approach is primarily based on instructor judgment of what events and decision points were important during the flight, and on relaxing the requirement that other aspects of the scenario follow the flight log exactly. The approach can be used both to create a scenario that is a quick, effective reproduction of the actual mishap, and also to create scenarios that contain the same kind of mishap but that look quite different from the original.

We begin this paper by briefly describing a primary source of flight data recorder (FDR) data and of noteworthy events defined from those data: the Military Flight Operations Quality Assurance (MFOQA) program. In subsequent sections we describe our approach to creating scenarios from these data, and ground the approach with an example. We then discuss elements of a tool suite that can be used to implement the approach, and conclude by discussing how such scenarios can be an effective part of a well-designed training program.

MILITARY FLIGHT OPERATIONS QUALITY ASSURANCE

“World-class organizations do not tolerate preventable accidents,” asserted Secretary of Defense Donald Rumsfeld in a memorandum that challenged the

military to reduce the number of mishaps and accident rates by 50% (Rumsfeld, 2003). Congruent with that objective, the Office of the Secretary of Defense issued a directive to establish policy for the MFOQA Process Implementation (Chu & Krieg, 2005). The MFOQA process "is the analysis and trending of aircraft flight performance and system data to proactively enhance safety, operations, training, and maintenance functions," (Armstrong, 2007). Prompted by numerous successes in commercial aviation FOQA programs, the military sought to exploit the benefits of enhanced on-board sensing, collecting, and transferring of all flight data to a knowledge management system.

The MFOQA program is working to represent FDR data in a nonproprietary format, and data capture as prescribed by MFOQA is sufficiently comprehensive to allow an aircrew to replay the full flight path of the mission. There are several classes of meaningful events defined for the flight data. A number of system developers provide desktop analysis and playback applications that permit review of all mission aspects, at any point in time, including aircraft performance (e.g., vertical speed), control inputs (e.g., rudder), and system function (e.g., fuel flow) shortly after the flight.

The military has already witnessed several successes in the early implementation of MFOQA even with only a few platforms networked. Data collected from C-17s showed a proclivity for excessive G-landings, particularly in nighttime assaults (Armstrong, 2007.) The MFOQA data helped identify this trend, for which adequate attention and retraining proved sufficient to mitigate the suboptimal technique, thereby increasing the safety of the operation and reducing landing gear replacements.

The MFOQA initiative will also help give rise to an enterprise system providing for more interoperable and sharable data. The ability to make analyses and reporting available across the Navy will enable aircrew, squadrons, and the fleet to compare findings, and learn from others' experience. The vision of collection for the "whole flight, every flight" would yield a vast data repository to support robust analysis of training needs, operational improvements, maintenance diagnostics, and performance baselines and thresholds. Most importantly, these findings can result in the discovery of precursors to mishaps. With the proper mitigation strategies such as training or procedure alteration, MFOQA could be a critical driver in averting mishaps.

In order to enable that training, it will be very useful to be able to generate scenarios from FDR flight logs and from MFOQA events.

Scenario Generation Using Flight Logs

Usually, scenarios in simulators for aircraft do not involve flight logs. Instead, they involve setting initial conditions in the simulator, and as the scenario progresses, the injection of relevant events such as partial equipment malfunctions, the appearance of unknown entities, or the sudden appearance of bad weather.

For reasons discussed above, precise data from flight logs from real or simulated flights can improve this picture, but only if the obstacles presented by precise flight data are overcome. The biggest one is that *flight logs leave no room for the trainee to fly*. At every moment during the flight, the aircraft from which the flight log originated had a specific location, elevation, heading, velocity, and so on. In the face of this, trainee controls have no effect.

The best that is possible is an annotated replay. This can be valuable, of course. Instructors and other experts can bookmark certain points for convenience in returning later, at which point they can fast forward, pause, comment, rewind, comment again, and so on. Unfortunately, it is also limited to having the trainee passively watch the replay. As discussed below, an opportunity for active learning is an important component of a well-designed training program. What is needed is a way for trainees to actively experience the mishap, and this involves allowing them at least some freedom of movement, so that the controls actually have an effect. It is easy to imagine that small deviations for the actual positions and velocities in the flight log will probably not have a noticeable effect on the circumstances that caused the mishap. The question is, how big can these deviations be without changing those circumstances?

This question deserves a systematic answer.

ELEMENTS OF A SOLUTION

For authoring and monitoring a flight-log-based scenario, there are three basic transformations of the original flight that are necessary: identification of the key events and decision points, generalizing those key events and decision points, and connecting those generalizations into an envelope. Different aspects of these steps receive more or less emphasis depending on instructor intent: for a quick recreation of the mishap itself, the important activity is to identify the key events and decision points; for creating superficially dissimilar

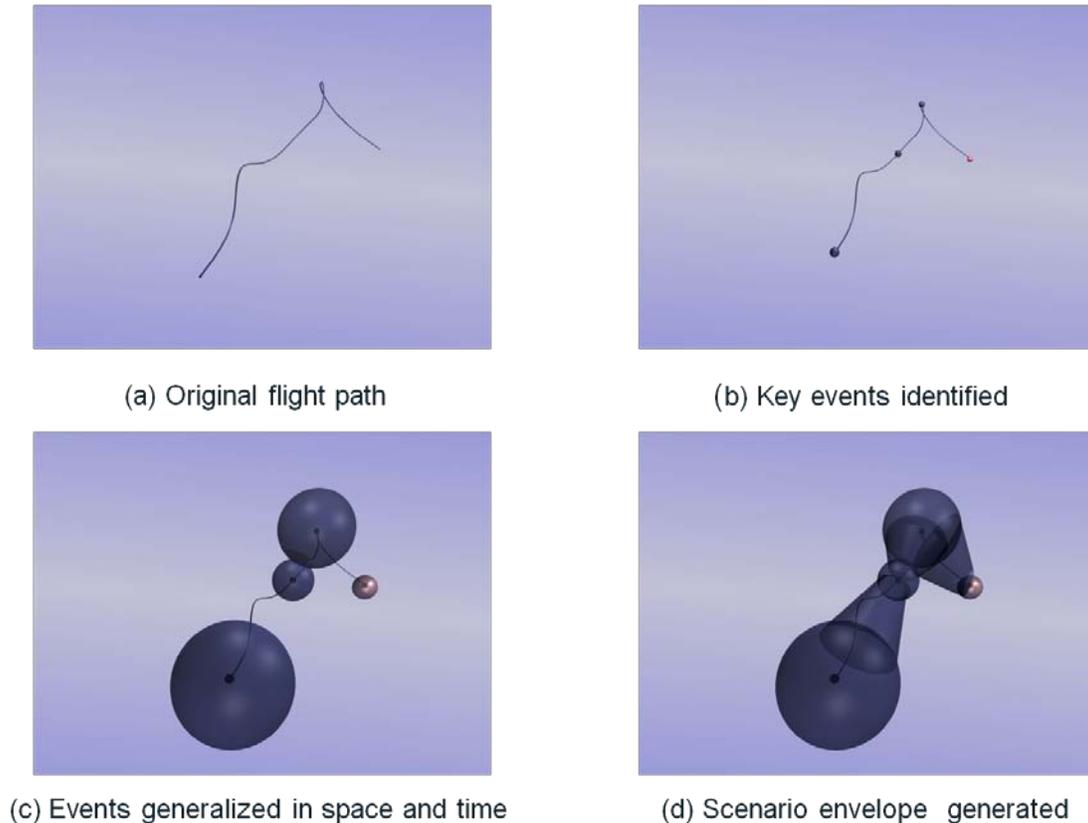


Figure 1. Steps in creating a scenario from a flight log.

scenarios that have the same underlying circumstances, the generalization step is emphasized. In both cases, the scenario envelope that is generated is used for monitoring.

Identifying Key Events and Decision Points

Figure 1 shows the steps involved in the creation of a mishap-related scenario. The original flight path (a) is provided from FDR data and MFOQA events, either from the actual aircraft or from a re-creation in a simulator. The FDR data and MFOQA events describe the exact state of the aircraft, its instruments, and its controls during the ill-fated flight. On the flight path, the author identifies key events of two kinds: (1) events that were out of the pilot's control that led up to the incident (the dark blue points in Figure 1b), and (2) pilot decision points that were key to causing or avoiding the incident (the light red point in Figure 1b).

Generalization

The next step is an important one: to generalize the key events and decision points, shown in Figure 1c by metaphorically turning discrete 3D points into larger 3D spheres. The generalization step is an

acknowledgement that a safety incident will never happen exactly the same way twice—the location, altitude, speed, or other aspects of the situation may be different from the original mishap, but it will still be the same kind of mishap. For each event and decision point, the scenario author specifies what is important for recreating the mishap and what is not

Suppose, for example, that the aircraft was at an altitude of 22,937 feet for the second (blue) key event. To recreate the mishap, it may only have been necessary that the altitude be greater than 15,000 feet in order for the incident to occur. This is a generalization. Identifying factors that had no effect on this particular mishap—say, weather or terrain—is another form of generalization. If some particular aspect of the flight must be exactly the same to recreate the mishap—if it cannot really be generalized—the author notes that as well. Other space-and-time-related specifics can also be generalized, as might specific states of instruments, controls, and other aircraft in the scenario. In effect, generalization turns specific events and decision points in the MFOQA log into 4D regions in space-time.

Creating and Monitoring the Scenario

The final step, Figure 1d, connects those 4D regions into a continuous envelope. This constitutes the scenario. As long as pilots stay within this envelope during the training mission, they will encounter the key set of circumstances involved in the mishap, and they will arrive at the mishap's critical decision points. They will be actively flying in a scenario based on, but not exactly the same as, the original mishap. They will have an opportunity to experience the mishap's circumstances and to take action accordingly. A beneficial side effect is that every use of the scenario will potentially be different. As a result, with repeated runs through the scenario, pilots will encounter a variety of conditions under which the mishap might occur, giving them more experiential variation, and thus a broader experience base.

AN EXAMPLE MISHAP

The process is easiest to understand with a realistic but partially fictional example centered around a pilot's misjudgment of the effects of low fuel on trying to land in worsening weather. In this example, the pilot was returning to Lemoore Naval Air Station from a low altitude training mission in the Panamint Valley. He was somewhat low on fuel, and he had reports that the visibility ceiling at Lemoore was dropping rapidly. Rather than landing safely at China Lake, though, he pressed ahead to Lemoore where he took off from. On reaching Lemoore, he discovered that the cloud ceiling was less than 200 ft., but he did not have enough fuel to land anywhere else. After an attempted approach on runway 32L he switched to an approach on runway 32R. He was unaware that the runway lighting was unusual on runway 32R, and as a result he missed the runway and brought his left wing in contact with the ground and right wheel in the mud. Figure 2 shows a map of the scenario.

To turn this mishap into a scenario, we start with the FDR log and the identified MFOQA events from the flight. These tell us the exact position, heading, and velocity of the aircraft as well as a number of internal variables such as remaining fuel. The next step is for the instructor to identify the key events and decision points in the flight, which may be seen in the first column of Table 1. The generalized conditions for those decision points may be seen in the second column

Table 1. Events, Decision Points, and Conditions for Example Scenario

Event or Decision Point	Conditions for Generalization
Mission Brief	<ol style="list-style-type: none"> 1. Locations of primary and secondary landing sites and training area 2. Current weather at primary and secondary landing sites 3. Predicted weather at primary and secondary landing sites at time of return 4. History of weather conditions at the landing sites
Pre-flight	<ol style="list-style-type: none"> 1. Bingo number calculated for return to primary landing site
Reach Bingo Point for return to base	<ol style="list-style-type: none"> 1. Fuel at 4.5 2. Distance to primary and secondary landing site 3. Ability to communicate with primary and secondary landing sites 4. Current and predicted weather conditions at primary and secondary landing sites. 5. At low altitude
Bingo point to secondary landing site reached	<ol style="list-style-type: none"> 1. Distance to primary and secondary landing site 2. Fuel amount at Bingo point for secondary landing site 3. All other alternate landing sites not available (e.g. KFAT)
Weather restricted approach	<ol style="list-style-type: none"> 1. Aircraft on approach 2. Fuel amount close to minimum for landing 3. No other airport within fuel range 4. Runway visibility less than minimums 5. Runways (in this case 32R and 32L) have different capabilities
Trainee stick control	<ol style="list-style-type: none"> 1. Panicked stick movement



Figure 2. Map of Example Mishap.

The events in the first column of Table 1 are then mapped to the flight timeline, and specific ranges of measures are provided whenever possible for the conditions in the second column. For convenience and efficiency, the instructor also may opt to edit out any portion of the timeline that is unnecessary. At this point, the scenario is ready for a new trainee to fly.

During the execution of the scenario, the instructor will ensure that the pilot stays within the scenario envelope either by alerting the trainee or by creating invisible barriers that the simulator cannot fly through. In this manner, the trainee is guaranteed to encounter all the key events, and is guaranteed to be in a position to make the key decision, in this case to land at China Lake or to continue on to Lemoore.

USING TOOLS TO CREATE THE SCENARIO

The process of creating scenarios from flight logs is enhanced with a suitable set of software-based tools. As Figure 3 shows, these tools are of two kinds, those for authoring and those for monitoring. The tools for authoring can be further subdivided into tools for identifying key events and decision points and tools for generalizing those decision points. Tools structured this way match exactly the approach outlined earlier, and in Figure 3 this is shown graphically with icons representing Figures 1b, 1c, and 1d adjacent to the tools' functions.

There are two different kinds of scenarios that these tools can generate. First, they assist instructors in the rapid creation of scenarios that are reasonably faithful to the mishap as described in the flight log. For this kind of scenario, instructors simply choose sensible waypoints (and other event points, if necessary), and the tools supply a little spatial and temporal "room" around them. The amount of spatial and temporal "slack" is a small and is the same for each event and decision point. Normally this is all that is required, but instructors can adjust spatial, temporal, and other constraints beyond this point if circumstances warrant. The result is a scenario that recreates the mishap from the flight log that requires minimal effort to construct.

The other kind of flight log based scenario is one that has the same underlying cause as the real mishap, but that on the surface looks different to the trainee. The instructor creates these by visiting each key event and decision point, and by generalizing it as much as possible. For example, the instructor might decide that, for a given event, terrain could change radically; an indent that involves Naval Air Stations at Lemoore and China Lake on the West Coast could instead involve Naval Air Stations at Oceana and Patuxent River on the East Coast. Similarly, the instructor might indicate that weather, fuel, temperature, equipment status, or other parameters can vary widely. From these generalizations, a scenario is constructed by choosing legal values for them at random, and this normally results in a very different-looking scenario, even though the important aspects of the underlying events and

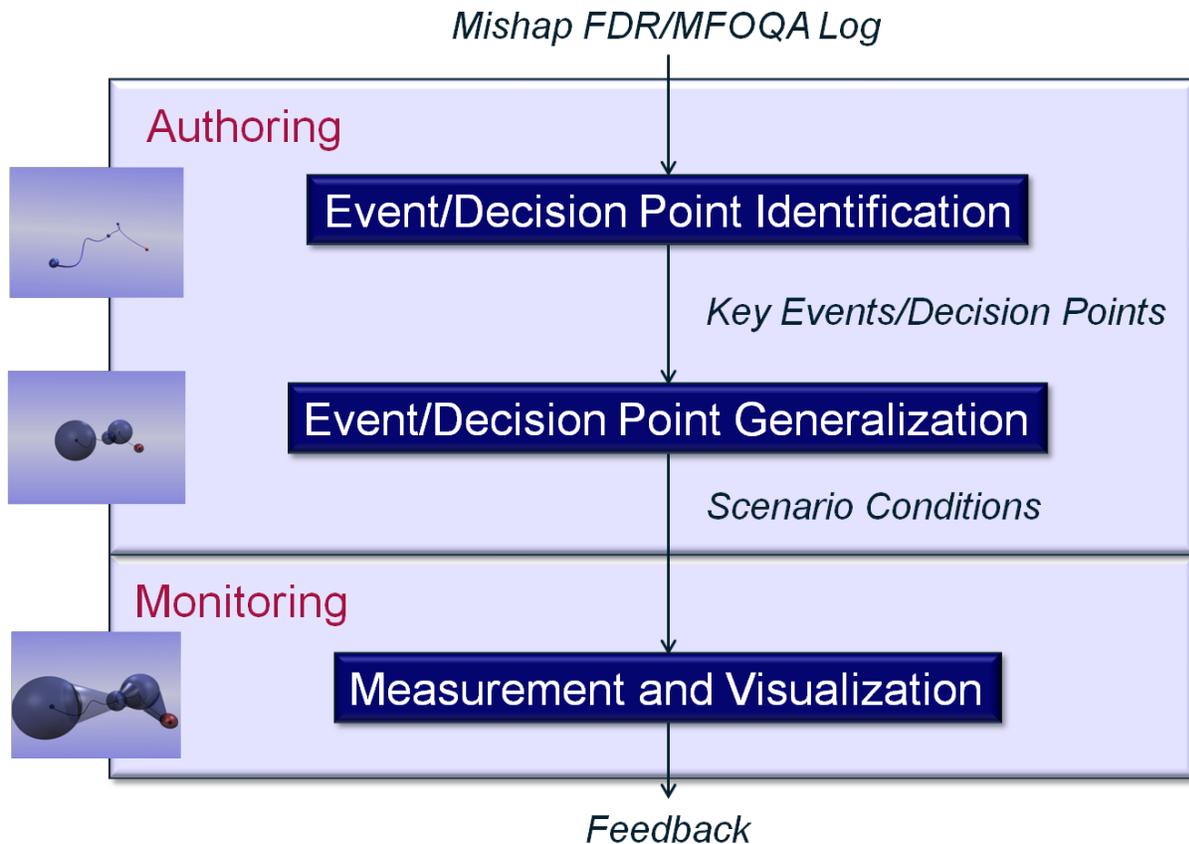


Figure 3. Components of a Scenario Engineering Toolset.

decision points have been preserved: trainees will find themselves in the same safely-related situation.

A notional authoring screen, illustrated in Figure 4a, shows the map with an overlay representing the flight path. The points on the flight path key events and decision points, the details of which are specified in the pane below the map.

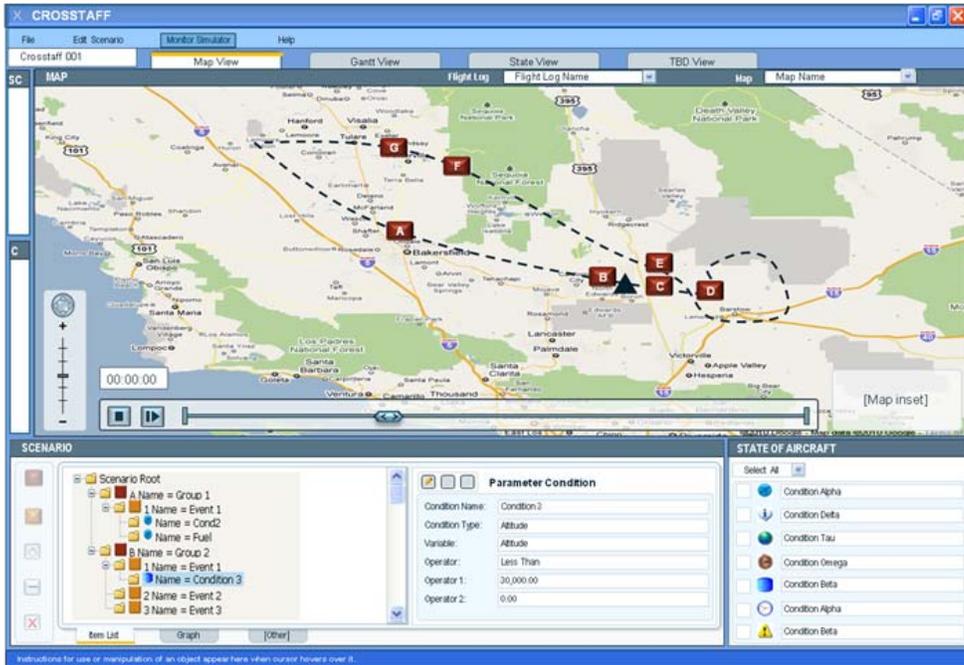
Figure 4b shows a corresponding notional monitoring screen. Here, the Gantt-chart-like representation indicates that the key events have a number of components whose timing is interrelated. This kind of event representation for a scenario will be useful, for example, when an instructor or a simulator operator needs to recreate a complicated series of equipment failures with certain constraints on timing. Other monitoring screens could show higher-level progress through the scenario.

Architecture of the Tool Set

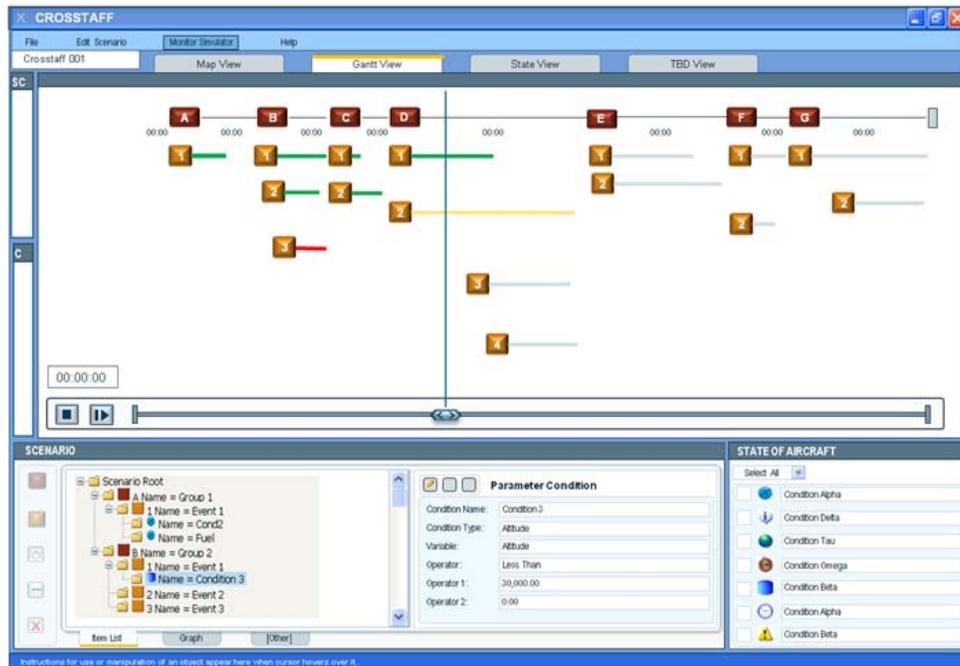
The toolset component architecture needs to support the two main modes of operation, Authoring and

Monitoring. The components in Figure 5 provide functionality for both modes. Input data are supplied from either a Flight Data Source (i.e., MFOQA recorder data or other mishap data), or from a Flight Simulation. Additional components are as follows:

- Visualization Manager – Provides the graphical user interface menus, forms, displays, and maps for user interaction.
- Scenario Manager – Provides Authoring functions to create, save, and restore scenarios from the Scenario Database.
- Decision Manager – Provides Authoring functions to instantiate and define conditions, events, and parameters defining the critical decision points of the training scenario using condition templates from the Condition Database.



(a)



(b)

Figure 4. Notional screen shots for scenario engineering system. (a) Authoring; (b) Monitoring.

- Flight Data Manager – Provides Authoring functions supporting the visualizations of flight replay or training flight preview from flight data from mishap logs or flight simulator logs, as well as supporting the creation of multiple flight tracks based on varying condition envelopes.
- Condition Engine – Provides data adapters in Authoring mode to retrieve Flight Data Source information from mishaps, or Flight Simulator replay data.
- Data Store – Includes the Scenario Database of scenario content and metadata as well as the real-time Condition Database containing measurements of the training session in progress

guaranteed to happen, but there might be other ways to cause the mishap. Other causes are necessary, that is, they must happen in order for the mishap to happen, but other events may be necessary as well. A mishap is amenable to training if *one* of the necessary causes, or *all* of the sufficient causes, can be eliminated with training.

For example, in the example mishap discussed earlier, the pilot’s decision to press ahead and land at NAS Lemoore, low fuel, a low ceiling, and the unusual configuration of lights on runway 32R are all necessary causes of the mishap—each condition was required. In order to prevent future mishaps, only one of these conditions, namely the pilot’s decision to continue, could have been modified with training, but that is enough—remove that decision, and the mishap would not have happened.

PEDAGOGICAL CONSIDERATIONS

Mishaps Suitable for Training

Not all aviation mishaps are suitable for training. Mishaps can be caused by, for example, equipment failures for which no training could compensate. Each mishap will have a causal chain of events—the immediate cause will have other causes, which will have other causes, and so on. Some causes are sufficient—that is, if they happen, the mishap is

The Training Program

To best prevent future mishaps of the same sort, simulator-based mishap scenarios should be embedded in an overall program of flight safety training that develops the cognitive skills that such challenging situations require.

Following Bransford, Brown, & Cocking (2000), we believe that effective learning systems must be learner-, knowledge-, assessment-, and community-centered.

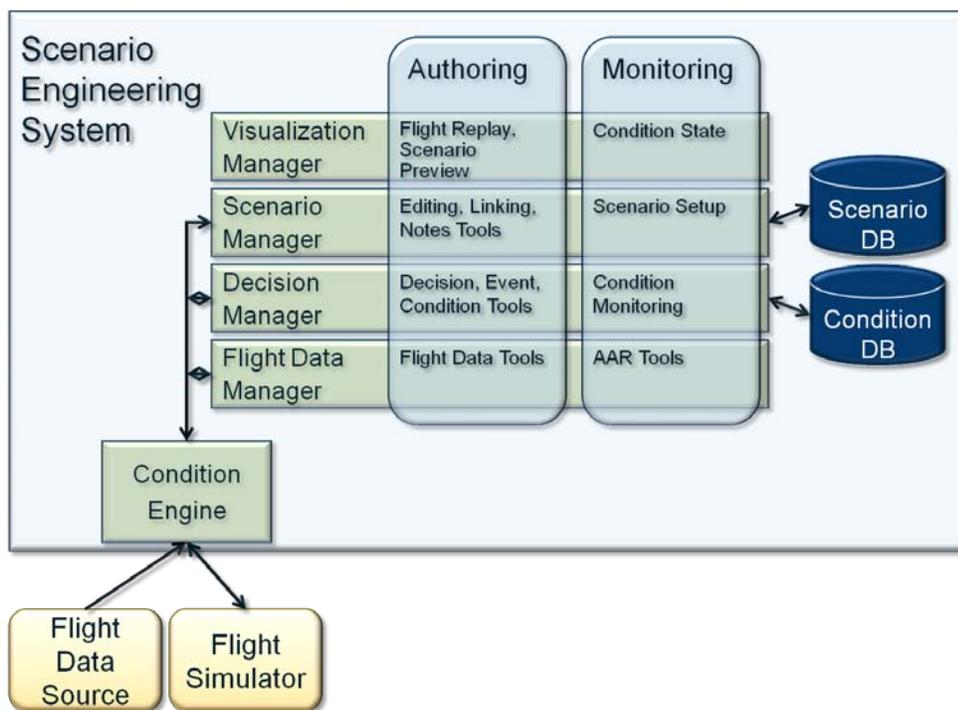


Figure 5. Notional architecture of a scenario engineering toolset.

Without due consideration of each of these elements, educational systems cannot reach their full potential. To be learner-centered, an educational system must be grounded in what learners bring to the table—what they know, what they do not know, what they need to learn, and what they are motivated to learn. To be knowledge-centered, effective educational systems must be rooted in well-structured bodies of knowledge that encourage deep understanding and reflection – sense-making rather than mere memorization. To be assessment-centered, learning systems must provide formative feedback – not only summative evaluation. To be community-centered, the learning environment must encourage exploration in an open environment and must be relevant to, and reflect, the community in which it is embedded.

An important component of this program emphasizes the importance of building deep and contextually rich knowledge through scenario-based experiences. Active engagement of learners is an important aspect of facilitating learning and comprehension, as supported by a large body of literature (e.g., Mayer, 1997; Soraci et al., 1999; Slamecka & Graf, 1978; Wittrock, 1989). The approach, therefore, relies heavily on scenarios and stories, as well as facts. Subject matter experts have assured us that grounding scenarios in actual mishaps guarantees engagement, and the fact that the scenario engineering approach described here can generate different-appearing but similarly-caused situations improves transfer of training. There is evidence that the transfer of skills from learning environments to other environments is enhanced by grounding instruction in a rich range of contexts (Brown, Collins & Duguid, 1989; Lintern, 1989; Liu, Williams, & Pedersen, 2002; Singley & Anderson, 1989).

But the ideal flight safety training program, in addition to the flight log based scenario component, will also have a didactic component. A combination of the two is important for effective learning and transfer (Bransford, Brown, and Cocking, 2000; Salas & Cannon-Bowers, 2001).

CONCLUSION

There are several unique and valuable benefits to the approach to creating scenarios from flight logs that we have described here:

- It is both easier and more precise to develop scenarios with MFOQA data as a starting place

than starting from scratch. The instructor has something to work from to identify decision points rather than generating them from scratch. Instructors directly identify the important factors for the incident. Recreation of scenarios closely resembling the mishap is fast and easy.

- Such scenarios extend the “reach” of instructors—tools to manage the process allow instructors to focus on instruction, and not on scenario conditions. This is especially true of scenarios that require a complex schedule of in-flight failures and other events.
- Likewise, when experienced instructors are scarce, scenarios as described here can help less experienced instructors create meaningful training experiences for the pilot. This is especially true of the scenarios that are a result of heavy generalization of causative events and that therefore (on the surface) do not resemble the original mishap.
- The generalization of events leads to substantial experiential variation, giving a high “replay value”: to the scenarios constructed this way. No two generalized flights will be exactly the same. It is harder for trainees to “game the system,” and knowledge and skill transfer should be high (Schmidt & Bjork, 1992.)

ACKNOWLEDGEMENTS

We would like to acknowledge the support of the Naval Air Warfare Center, Aircraft Division, especially Dean Carico, and NAVAIR Program Manager for Aviation 205, especially LT Melissa Denihan and Laura Biggerstaff, for their strong support of this effort. We would also like to thank CDR Matthew Hebert for fruitful discussions about Class A mishaps. The opinions expressed here are those of the authors and do not necessarily reflect the official position of the sponsors or the Department of Defense.

REFERENCES

- Armstrong, K. (2007). MFOQA- How we got here and where we're going. *Flying Safety*, May, 2007.
- Baddeley, A.D. (1992). Working memory. *Science*, **255**, 556-559.
- Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind,*

- experience, & school. Washington, DC: National Academy Press.
- Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, **18**, 32-41.
- Chu, D. & Krieg, K. (2005). Military flight operations quality assurance (MFOQA) process implementation. *Office of the Secretary of Defense Memorandum*.
<https://www.denix.osd.mil/portal/page/portal/SHF/References/MFOQA-Policy-Memo.pdf>
- Lintern, G. (1989). The learning strategies program: Concluding remarks. *Acta Psychologica*, **71**, 301-309
- Liu, M, Williams, D., & Pedersen, S. (2002). Alien Rescue: A Problem-Based Hypermedia Learning Environment for Middle School Science. *Journal of Educational Technology Systems*, **30**(3).
- Mayer, R.E. (1997). Multimedia Learning: Are We Asking the Right Questions? *Educational Psychologist*, **32**, 1-19.
- Rumsfeld, D. (2003). Reducing preventable accidents. *Office of the Secretary of Defense Memorandum*.
http://www.dodig.mil/Inspections/IE/sdp_timeline/SecDef%20Memo,%20May%2019,%202003.pdf
- Salas, E., & Cannon-Bowers, J.A. (2001). The science of training: A decade of progress. *Annual Review of Psychology*, **52**, 471-499.
- Schmidt, R.A. & Bjork, R.A. (1992). New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychological Science*, **3**(4), 207-217.
- Singley, M.K. & Anderson, J.R. (1989). *The transfer of cognitive skill*. Cambridge, MA: Harvard University Press.
- Slamecka, N.J., Graf, P. (1978). The generation effect: Delineation of a phenomenon. *Journal of Experimental Psychology: Human Learning & Memory*, **4**, 592-604.
- Soraci, S.A, Carlin, M.T, Chechile, R.A, Franks, J.J, Wills, T., and Watanabe, T. (1999). *Encoding Variability and Cuing in Generative Processing*. *Journal of Memory & Language*, **41**, 541-559.
- Wittrock, M.C. (1989). *Generative Processes of Comprehension*. *Educational Psychologist*, **24**, 345-376.