Journal of the National Academy of Forensic Engineers®

NATIONAL ACADEMY OF FORENSIC ENGINEERS

http://www.nafe.org
ISSN: 2379-3252

Vol. XXVI No. 1 June 2009

Forensic Engineering and the Scientific Method

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Abstract

The scientific method is utilized in order to understand the relationship among observations of physical phenomena, while minimizing the influence of human bias and maximizing objectivity. Specific procedures for the application of the scientific method vary from one field of science to another, but the investigative technique universally provides for an analytical framework to acquire, collect and/or integrate knowledge. Engineering forensics involves the analysis of the parameters or cause(s) of incidents or failures and/or hypothetical prevention methods. Engineering analysis of forensic problems is a multifaceted, multidisciplinary pursuit that is often wide in scope. Forensic engineering generally applies existing science in conjunction with the knowledge, education, experience, training and skill of the practitioner to seek solution(s). The scientific method, including definition of a null hypothesis, is rarely utilized in forensics as new science is rarely required. A forensic engineering investigation typically involves the application of long established science (Newton's Laws, for example). Forensic engineering encompasses the systematic search for knowledge necessitating the observation and definition of a problem; the collection of data through observation, research, experimentation and/or calculation; the analysis of data; and the development and evaluation of findings and opinions. The ultimate objective of a forensic engineering investigation is uncompromised data collection and systematically considered, iteratively derived and objectively balanced conclusions.

Introduction and Definition

The scientific method, as it is traditionally applied to new science, involves the methodological formulation of hypotheses and collection of data to test the hypotheses specifically via experimentation (Figure 1). In forensic engineering, the incident under analysis typically has already occurred; the issue then most often involves the establishment of factors of causation or prevention. Hence, the formation of hypotheses is most often not required. In engineering forensics, there are often many factors contributing to an event. The engineer forms an opinion, which is drawn after the data is iteratively collected and collectively analyzed. The forensic engineering method encompasses the systematic search

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for knowledge necessitating the observation and definition of a problem; the collection of data through observation, research, experimentation and/or calculation; the analysis of data; and the development and evaluation of findings and opinions (Figure 2). Both the scientific method and the forensic engineering method are iterative processes. The outcome of either method can be excluded by further research.

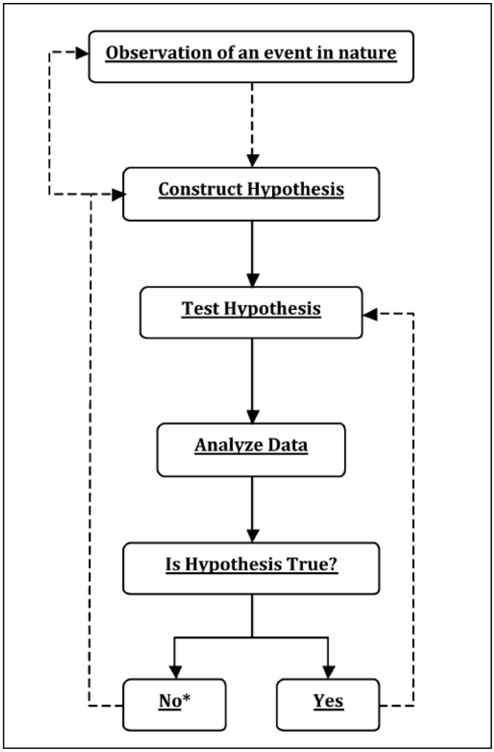

Figure 1
Flowchart Illustrating the Scientific Method

* Reconstruct hypothesis and/or re-observe phenomenon

While SCIENCE can be defined most succinctly as a department of systemized knowledge, ENGINEERING can be defined most narrowly as the application of science. Forensic engineering applies science and mathematics by which the properties of matter and the sources of energy are made useful. Some have defined *engineering* as the art of applying science, and/or stated that engineering has a creative aspect which is most observable in engineering design.[1] Generally, science attempts to understand what already exists; engineering commonly uses existing science or technology for useful innovative purpose; and forensic engineering seeks to determine cause and prevention. It can be argued that engineers may exercise science, and scientists may also exercise engineering so in practice the delineation is a function of the specific work undertaken. Rather than acting as scientists in developing new science, forensic engineers apply existing science or technology via scientific and/or engineering principles to solve problems. From the mathematical modeling or calculation standpoint, the scientific principles applied by forensic engineers may, for example, make use of Newton's Laws of Motion, validated via the scientific method. Thus the scientific method would be intrinsic in Newtonian engineering calculations and analysis.

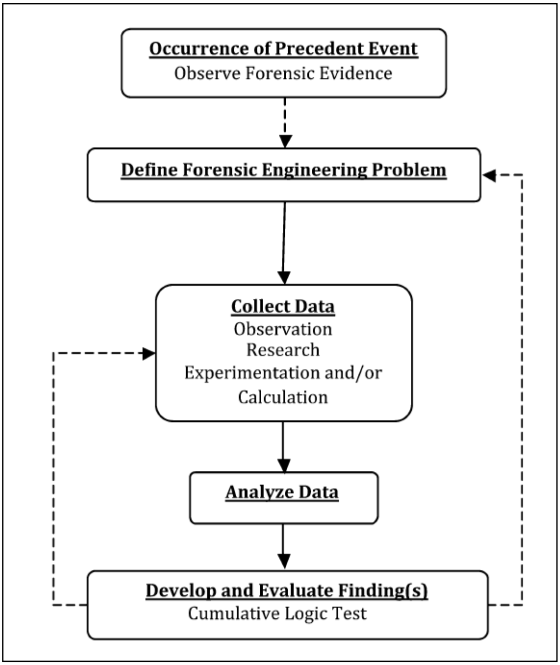

Figure 2
Flowchart Illustrating the Forensic Engineering Method Utilized in Applied Science or Technology

The Forensic Engineering Method

A forensic engineering analysis is a multifaceted examination utilizing uncompromised observation with knowledge, education, experience, training and skill. The forensic engineering method rarely utilizes a hypothesis because forensic engineering most often involves the application of pre-existing science or technology. The forensic engineering analysis is accomplished by first defining the problem related to a precedent event (as illustrated in Figure 2). Data carefully collected and analyzed yields findings that are iteratively developed to minimize bias and maximize objectivity. After the analysis has been iteratively validated, results, findings and/or conclusions are formulated.

Define the Forensic Engineering Problem

Most simply, the forensic engineering problem starts as the assignment and may change as new factual data is discovered and as the iterative process of data collection progresses. Often, engineers with a specialty in forensics are asked to evaluate whether the incident or product failure could have occurred as described by witnesses based on the available forensic evidence. The engineer may be asked whether a set of alternative facts or different environmental factors would affect the outcome of the incident. If the data collection process reveals an unanticipated variable or causal factor, the forensic engineering problem may require narrowing, expansion and/or redefinition. Cumulative logic is a process where the evidence is considered individually and collectively. If the driving variables collectively support a finding, iteration may not be required. If not, the engineer may decide not to redefine the problem. This parallels the Yes/No decision in the scientific method except cumulative logic reflects a reasonable degree of certainty, rather than satisfying a scientific null hypothesis. Recall that hypotheses may only be disproven via a null hypothesis rather than proven.

Collect Data: Observation, Research, Experimentation and/or Calculation

The scientific method relies on statistically analyzed experimentation for the falsification or validation of a null hypothesis. Controlled experiments can help to determine the plausibility of an occurrence or event under a limited set of defined circumstances. In engineering forensics, designing a variable controlled experiment may not be possible since replicating complex interactions of variables that simultaneously exist in real world events may not be possible. Due to the innate variability in real world systems, statistical significance in full scale forensic engineering experimentation is uncommonly achieved. The unique variability of human anthropomentics, human interaction within a system as well as transitory and potentially adverse incident site conditions most often precludes single variable controlled testing. Testing may also not be possible in other circumstances where a specific incident cannot be practically replicated in a laboratory environment; for example, the experimental expense may be disproportionally financially burdensome and/or unreasonably unsafe.

In such circumstances, courts often have been satisfied with testimony that is based on other indicia of reliability that are well-grounded in the facts of the circumstance (*Martinez v. Altec Industries, Inc.,* 2005 WL 1862677 (M.D. Fla. 2005). In these scenarios, acquisition of data based on generally accepted research practices and peer-reviewed testing has been an acceptable alternative (see *Bitler v. A.O. Smith Corp*., 391 F.3d 1114 (10th Cir. 2004) where an expert performed a standard fire investigation procedure of observing conditions at the scene and deduced the cause of the incident. The court determined that the expert's methods were not susceptible to testing or peer review, but were generally accepted within the field of fire investigation). Peer review and general acceptance is required by Frye and Daubert, respectively, for new science in which the judiciary is empowered to determine if evidence is admissible. When generally accepted existing science is applied to analyze a forensic engineering problem, review by colleagues of routine calculations/methods that have been regularly relied upon by engineers is not necessary. In circumstances where new processes or methods are used, engineers may opt to send their analyses to colleague(s) for review because the narrow esoteric questions at issue in litigation may not be of sufficient interest for publication.

Analyze Data

In engineering forensics, analysis and proper interpretation of data relies heavily upon knowledge, experience and training. Once the engineer has observed available relevant forensic evidence and collected data including observation, research, experimentation and/or calculation, the next step in the process is analysis. Information gleaned from the observed evidence and data can be compared to known benchmarks (i.e. tolerances and/or standards) and evaluated for internal consistency and cumulative consistency in logic. As an example, the purpose of analysis may be to quantify accelerations and forces in a structure or system and weigh those against tolerances or limits that characterize failure in specific modes. If the tolerances or limiting kinematics/kinetics are exceeded, the structure (whether it be a suspension bridge or biological tissue) is assumed to yield to failure.

In certain cases according to some courts, the analysis can simply involve logical reasoning or may rely on extensive experience and training when analyzing an event (see *Compton v. Subaru of Am., Inc*., 82 F.3d 1513 (10th Cir. 1996), wherein the expert's testimony "was not based on any particular methodology or technique. Rather, he reached his expert conclusions by drawing upon general engineering principles and his 22 years of experience as an automotive engineer"). Per the Court decision, the engineering analysis may be conducted utilizing knowledge, education, experience, training and skill.

General engineering principles such as physics and mathematics can be applied in order to analyze whether specific scenarios are plausible. (See e.g., *Vienne v. American Honda Motor Co*., 2001 WL 43598 (E.D. La. Jan. 16, 2001) wherein the court found that the expert's opinions "[were] based on the laws of physics and on routine calculations that have been tested, peer reviewed, and regularly relied upon by engineers in accident reconstruction.")

Sometimes, incidents analyzed by engineers will be associated with limited forensic evidence and/or data. For example, an airplane crash at sea where the aircraft and casualties are never recovered, may only have a final pilot transmission or radar reading. The findings should fit the limitations of the data, even if to say that there is insufficient data or the issue is indeterminate. For example, in automobile collisions or product designs, damage evidence may be repaired or destroyed. Experience is used to determine what findings fit limited evidence. Conservative findings that may include safety factors and/or report engineering ranges based upon known data points may be appropriate with limitations clearly stated.

Develop and Evaluate Opinions: Cumulative Logic Test

The result of the forensic engineering method is systematically organized and re-iteratively derived findings. When a forensic engineering problem requires new science, the scientific method can be utilized. The cumulative logic test analyzes whether the weight of supplemental data is consistent or inconsistent with existing data within a reasonable degree of engineering certainty. If inconsistent, the forensic engineering problem may have to be redefined, additional data collected and/or reported indeterminate.

Opinions, findings and/or conclusions should generally be presented as a most likely cause or within a reasonable degree of engineering certainty, rather than a fact in recognition that the findings are based on available forensic evidence. In some situations, it may be possible for the forensic engineer to express opinions with greater certainty based on the data exposed. Validation of a working theory is limited by the state-of-the-art in technology and the number of variables compared to unknowns. If the forensic evidence is not consistent with the reported scenario, it may be concluded (at least in part) that the event did not occur in the manner opined. Again, the testing or analysis may yield indeterminacy, and this is a valid finding. Although the forensic evidence may be consistent with the reported scenario, this does not rule out that the evidence may also be consistent (or more consistent) with alternate scenarios. The engineer may assemble and analyze all pieces of the forensic puzzle and opt to report scenarios that are likely.

The assessment of the opinion should generally involve a logic test based on the cumulative knowledge acquired relating to the event in question. This important test involves the critical evaluation of facts and data. Essentially, the engineer analyses the problem utilizing the body of scientifically based knowledge gained throughout the investigation by applying scientific principles and deductive thought reasoning. If the opinion is not supported by the data uncovered during investigation, the process may be re-iterated or the work concluded. The process of data collection (via observation, research, experimentation and/or calculation) should be ongoing until feasible scenarios have been evaluated. When analysis and investigation yield a mixed result (where some analytical elements support a specific scenario and some analytical elements likely rule out that same scenario), the engineer simply reports the mixed result.

Discussion: Data Limitations, New Methods and Legal Considerations

Due to the nature of real world forensics, there are situations in which evidence may be limited or variables too vast and/or financially burdensome to isolate in testing. As a simple example, in an product design analysis, although the product may be destroyed, photographs or repair estimates may be available. The engineer determines if the findings can be scaled to the weight of the data available with obtainable evidence. In some cases, the error range may need to be widened due to the limits of physical evidence available. For example, in an automotive incident where limited physical evidence indicates that the velocity of the impact was < A mph, the finding might be stated as velocity at impact < A or < A +/- X% to create a margin (+/- X% is an example of a safety or sensitivity factor) to report the analytical results within a reasonable degree of engineering certainty. Existing evidence and data is a function of the state of knowledge and the nature of the problem at hand and should be utilized for interpolation between data points rather than extrapolation beyond the data. When the data and/or observational information prove insufficient or inconclusive, the solution to the forensic problem may simply be indeterminate.

Many forensic engineering methods have long been established. However, when entirely new methodologies that have not secured general acceptance are undertaken, these may be reviewed by others and/or presented to reflect any limitations.

Frye, Daubert and Kumho are often cited standards for admissibility of forensic engineering and other expert testimony. Although *Frye and Daubert* specifically apply to new scientific evidence, *Kuhmo*, however, applies to 'technical' or 'other specialized' knowledge and may be most relevant to the engineering application of existing science. The *Frye* standard includes that the testimony of a scientist possessing either credentials, experience, skill or training is admissible if based on "generally accepted" methodology. The *Daubert* standard specifically requires that conclusions made by a scientific expert will qualify as scientific knowledge if demonstrated that it is the product of sound "scientific methodology" or was derived from the scientific method and/or peer reviewed. Engineers should provide documentation of the method utilized. "General acceptance" is also a factor weighing in favor of admissibility. In *Kumho*, the Supreme Court indicated the court must examine the proffered testimony to determine that it is based on the methods and procedures that result in the "same level of intellectual rigor" that is common to the engineering profession, as practiced outside of the courtroom. In making this assessment, the court may consider the factors presented in *Daubert*. The Court further noted that it would be difficult to distinguish "between 'scientific' knowledge and 'technical' or 'other specialized' knowledge, since there is no clear line dividing one from the others … ."

The Federal Rule regarding expert testimony was amended subsequent to the *Daubert* ruling. Federal Rule 702 allows a forensic engineer to offer expert opinions if the testimony "will assist the trier of fact in understanding the evidence," and if the witness is "qualified as an expert by knowledge, skill, experience, training or education," and the forensic expert offers testimony that: 1) is based upon sufficient facts or data, 2) is the product of reliable principles and methods, and 3) applies the principles and methods reliably to the facts of the case.

Conclusion

An engineering forensic analysis is a multifaceted endeavor requiring engineering knowledge and education as well as supplemental experience, training and skill in forensics. The generally accepted Forensic Engineering Method applies to engineering as well as some physical science disciplines including metallurgy, electrical, mechanical, biomedical, environmental, aerospace, materials science and physics. Although more broadly applicable, it is termed the Forensic Engineering Method.

Because forensics requires analysis of an incident that has previously occurred, the method is different from the scientific method utilizing controlled variable null hypothesis testing. This documents the differentiation between the traditional scientific method utilized by scientists, and the longstanding, commonly practiced and generally accepted method used in engineering to solve forensic problems. The features distinguishing the forensic engineering method are a function of the fact that most, if not nearly all, forensic problems require use of existing science and/or technology. In contrast, the scientific method tests new science. Engineers working on a forensic problem most often utilize routine methods and calculations that are intrinsically generally accepted like Newton's Laws but may not be published due to the lack of uniqueness and/or narrow application, esoteric and incident specific nature of the majority of forensic issues. Due to the complex, real world, multiple variable nature of engineering forensic problems, it is rare to isolate or control for numerous forensic variables as required in scientific null hypothesis testing. This paper outlines the long standing and widely utilized Forensic Engineering Method. The ultimate objective of the Forensic Engineering Method formally published here is uncompromised data collection and systematically considered, iteratively derived and objectively balanced conclusions.

Acknowledgements

I would like to thank my colleague, Joe Cecil Ph.D., J.D., Federal Judicial Center, Program on Scientific and Technical Evidence, Washington, D.C. for his invaluable input.

Special thanks also to an exceptional team of reviewers including:

Lindley Manning, P.E., Professor, Mechanical Engineering, University of Nevada at Reno.

Marvin M. Specter, P.E., L.S. Founding Pres. and Exec. Director, NAFE.

Robert Anderson, Ph.D., P.E., Emeritus Professor: Materials Engineering, School of Engineering, San Jose State University, San Jose, CA; Associate Professor, Metallurgy: School of Earth Sciences, Stanford University, Stanford, CA.

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Reference

1. The Morrill Act (1862) marked the first Federal aid to higher education and made it possible for new western states to establish colleges for their citizens. The new land-grant institutions, which emphasized agriculture and the MECHANIC ARTS, which evolved into the field now known as engineering.