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# INVESTIGATION AND ROOT CAUSE ANALYSIS GUIDELINE FOR UNDETECTED CRACKING INCIDENTS IN SAFETY-OF-FLIGHT AIRCRAFT STRUCTURE

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This document provides guidance for investigating and conducting root cause analyses of safety-related incidents associated with Air Force maintenance actions. The impetus for and sole focus of this document are incidents in which detectable cracks in safety-of-flight aircraft structure have been missed by approved nondestructive inspection (NDI) techniques. The tools defined herein, however, can be adapted and utilized for the investigation of any maintenance-related incident.

The role of root cause analysis in incident investigation is emphasized in this document. Root cause analysis is intended to answer the questions "What?," "How?," and, most importantly, "Why?" regarding an incident. A successful root cause analysis will identify the, controllable, causal factors that can be corrected to eliminate the recurrence of similar incidents in the future.

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# ABSTRACT

This document provides guidance for investigating and conducting root cause analyses of safety-related incidents associated with Air Force maintenance actions. The impetus for and sole focus of this document are incidents in which detectable cracks in safety-of-flight aircraft structure have been missed by approved nondestructive inspection (NDI) techniques. The tools defined herein, however, can be adapted and utilized for the investigation of any maintenance-related incident.

The role of root cause analysis in incident investigation is emphasized in this document. Root cause analysis is intended to answer the questions “What?,” “How?,” and, most importantly, “Why?” regarding an incident. A successful root cause analysis will identify the, controllable, causal factors that can be corrected to eliminate the recurrence of similar incidents in the future.

This document provides a discussion of methodologies, instructions, and worksheets that may be used in a root cause analysis. Though there are numerous methods to use when conducting a root cause analysis, this guide provides focuses on the application of the following four methods:

- Sequential Events and Causal Factor Analysis (Appendix A)
- Cause and Effect Analysis (Appendix B)
- Change Analysis (Appendix C)
- Human Performance Evaluation (Appendix D)

# 1. SUMMARY

This document is a guide for conducting investigations of failed systems, processes or components, specifically those related to incidents in which otherwise detectable cracks in safety-of-flight aircraft structure were missed during a nondestructive inspection (NDI) process. The basic reason for investigating and reporting the causes of incidents is to enable the identification of corrective actions that are adequate to prevent recurrence and thereby protect the safety-of-flight of Air Force weapons systems as well as to ensure the safety of the pilots, passengers, maintainers and the civilian community.

Root cause analysis is a key component of these investigations. During a root cause analysis, numerous causal factors (i.e. "causes) may be identified. Identification of causal factors ensures that deficiencies within the control of the inspection organization and processes are also identified. This, in turn, guides early corrective actions and controls. Therefore, root cause analysis is central to ensuring robust maintenance practices are maintained.

Root cause analyses identify the "what," the "how," and the "why" associated with incidents that are investigated. A successful root cause analysis will identify the controllable, causal factors that can be corrected to eliminate the recurrence of similar incidents in the future.

One may perform a root cause analysis using a number of different methods. This guide recommends and summarizes methods which appear to be most applicable to analyzing inspection related incidents in the U.S. Air Force; however, the basic approach and root cause analysis techniques described in this document can apply to the investigation of any type of failure of a system, process, or component.

The level of effort expended on such analyses should be commensurate with the significance or severity of the incident. Most off-normal incidents will require only a scaled down effort while most emergency incidents should be investigated using one or more of the formal analytical models.

The DOE Root Cause Analysis Guidance DOE-NE-STD-1004-92 was a significant source in the development of this document. Other resources were also utilized and are enumerated in the reference list.

# 2. INVESTIGATION PHASES

**(Methodology and Phases to Investigate Undetected Cracking Incidents in Safety-of-Flight Aircraft Structures)**

When investigating the root cause of inspection related incidents the following methodology should be followed:

Step 1. Identify the incident as a Type (I, II, or III), using the guidance of Table 1, based on the circumstances surrounding the incident.

Step 2. Identify the root-cause analysis methods that should be applied by using the guidance of Table 1.

Step 3. Form the investigation team (Refer to Section 4) based on the resources end expertise required to complete the investigation.

Step 4. Conduct the five-phased root cause investigation (see details below). Use the attached appendices for guidance on performing the various recommended root-cause analysis methods.

Keep in mind that regardless of the method(s) used for a root cause analysis, the overall investigation and reporting process (Step 4) should include the five phases as highlighted below. While there may be some overlap between phases, every effort should be made to keep them separate and distinct. Management involvement and adequate allocation of resources are essential to successfully execute the five investigation and reporting phases.

**Phase I. Collecting** In order to minimize the loss of data and information, it is important to begin the data collection phase of any investigation immediately following the incident. The information that should be collected consists of: a) conditions before, during, and after the incident, b) personnel involvement (including actions taken), c) environmental factors d) historical data and e) other information having relevance to the incident. (Details for conducting Phase I can be found in Section 6).

**Phase II. Analyzing** This phase consists of the root cause analysis. Any root cause analysis method may be used that includes the following steps (Details for conducting Phase II can be found in Section 7):

1. Identify the problem.

2. Determine the significance of the problem.

3. Identify the causes (conditions or actions) immediately preceding and surrounding the problem.

4. Identify the reasons why the causes existed, working back to the root causes (the fundamental reason which, if corrected, will prevent recurrence of these and similar incidents). Identification of the root causes concludes the analysis (or assessment) phase.

**Phase III. Correcting.** Implementing effective corrective actions for each root cause reduces the probability that a problem will recur, improves reliability, and enhances safety. (Details for conducting Phase III can be found in Section 8).

**Phase IV. Informing.** Management and personnel involved with the incident should be informed of the results of any investigation. Key information that should be reported includes findings, the results of the root cause analysis, and all corrective actions recommended and/or implemented. Consideration should also be given for distributing the results of the investigation to other pertinent organizations (Details for conducting Phase IV can be found in Section 9).

**Phase V. Verifying.** This phase includes determining if corrective action has been effective in resolving problems. An effectiveness review is essential to ensure that corrective actions have been implemented and are preventing recurrence. Management involvement and adequate allocation of resources are essential to successful execution of the five investigations and reporting phases (Details for conducting Phase V can be found in Section 10).

# 3. DEFINITIONS

**Causal Factor (Cause)** - A condition or an event that results in a failure or incident (anything that shapes or influences the outcome). For example: a) poor signal-to-noise ratios in inspection instruments, b) failures to follow defined procedures, c) failure to validate procedures, d) weaknesses or deficiencies in management or administration.

**Causal Factor Chain (Sequence of Events and Causal Factors)** - A cause and effect sequence in which a specific action creates a condition that contributes to, or results in, an event. Each event may create new conditions that, in turn, contribute to or result in another incident. The sequence of events ultimately leads to the incident under investigation.

**Condition** - Any as-found state, whether or not resulting from an event, that may have adverse safety, operational, readiness, or mission capability implications. An (existing) error in assumed detectable flaw size, an anomaly associated with (resulting from) design or performance, poorly written procedures or an item indicating a weakness in the management process are four example conditions.

**Contributing Cause** - A cause that contributed to an incident but, by itself, would not have caused the incident. For example, in the case of the failure of an inspection to detect a large crack in safety-of-flight structure, a contributing cause could be an inspector's fatigue reducing the inspectors focus to the task. This condition, by itself, was not a direct or root causal factor.

**Crack Lengths** - Various crack lengths are of interest when performing a root cause analysis of cracks that are undetected by nondestructive inspection techniques. Many of these crack lengths are graphically defined in Figure 1. These crack lengths include:

$a_0$, $a_i$, or $a_{init}$ – the length of the starting, inherent, or initial crack existing within a structure at the time of manufacture

$a_{NDI}$ – the length of the largest crack that an NDI method can miss based upon probability of detection (POD) studies and usually corresponding to a "90/95" crack length (i.e. a crack length that can be found 90% of the time with 95% confidence). Also known as the "minimum detectable crack size."

$a_{miss}$ – the length of a crack missed (undetected) by a nondestructive inspection

$a_{critical}$, $a_{crit}$, or $a_{cr}$ – the critical length of a crack above which the crack will grow catastrophically to failure upon the application of the next design limit load cycle.

$a_{cr\text{-}miss}$ – the length of a crack that, if missed (undetected) by a nondestructive inspection, will grow catastrophically to failure (i.e. to $a_{crit}$) before the next inspection

**Direct Cause** - The cause that directly resulted in the incident. For example: If during the laboratory development of an inspection, the technique was found to be capable of detecting a given size crack; however after the procedure was fielded, cracks of the same size were missed in during subsequent inspections. In this case a direct cause could be failure to issue clear and accurate inspection procedures.

**Event** - An event can be thought of as a "building block" of an incident. A sequence or chain of events leads up to the incident being investigated.

**Facility** - Any organization or location that fulfills a specific purpose. Examples include Air Logistics Centers (ALC's), field-level inspection laboratories, flight-lines, maintenance facilities, firms conducting inspections under contract, and any location or organization where and inspection or maintenance actions occur.

**Incident (Failure Event)** - The failure of a system, process, or component that has the potential to seriously impact safety and/or mission capability. An incident is usually comprised of a series of events brought about by the interaction of a number of causes. For the purposes of this guide, incidents are failures of nondestructive inspection processes to detect cracks in safety-of-flight aircraft structures. Such failures (incidents) may be classified into three general categories described below in Figure 1 and in Table 1:

**Type I Incident** - A Type I incident is any incident that resulted in or could result in a Class A mishap or that poses a high risk to flight safety or mission capability. The consequences of a Type I incident are a loss of life or aircraft or effects which would result in a Class A mishap.

An undetected crack incident is classified as Type I if a crack with length $a_{miss}$ is undetected and if $a_{miss} \geq a_{cr\text{-}miss}$. In this case, the undetected crack with length $a_{miss}$ can grow to a length of $a_{critical}$ in a period that is less than one inspection interval (i.e. it can grow to length of $a_{critical}$ before the next inspection)

Type I incidents require the use and documentation of a formal root cause analysis method to identify the causal factors and program deficiencies. The Sequential Events and Causal Factor Analysis, Change Analysis, and Cause & Effect Analysis methods should all be used together in an extensive investigation of the causal factor chain. Human Performance Evaluation may also be required for Type I incidents if warranted.

**Type II Incident** - A Type II incident is any incident that poses a moderate risk to flight safety and/or mission capability. The consequences of a Type II incident are major readiness or economic impacts.

An undetected crack incident is classified as Type II if a crack with length $a_{miss}$ is undetected and if $a_{NDI} \leq a_{miss} < a_{cr\text{-}miss}$. In this case, the undetected crack with length $a_{miss}$ cannot grow to a length of $a_{critical}$ in a period that is less than one inspection interval (i.e. it cannot grow to length of $a_{critical}$ before the next inspection).

The investigation of a Type II incident requires, at a minimum, the use of the Sequential Events and Causal Factor Analysis and Cause & Effect Analysis methods. The Change Analysis and Human Performance Evaluation methods may also be required for Type II incidents if warranted.

**Type III Incident** - A Type III incident is any incident that poses a low risk to flight safety or mission capability but that may be an indication of wider program issues that require attention. Type III incidents may not have any significant consequences beyond the need to apply standard repairs (find and fix).

An undetected crack incident is classified as Type III if a crack with length $a_{miss}$ is undetected and if $a_{miss} < a_{NDI}$. In this case, the undetected crack with length $a_{miss}$ cannot grow to a length of $a_{critical}$ in a period that is less than two inspection intervals (i.e. it cannot grow to length of $a_{critical}$ before two inspections have been performed). It is expected that the next inspection interval will detect these cracks before they grow to length $a_{cr\text{-}miss}$.

Type III incidents require, at a minimum, gathering information and drawing conclusions without requiring the use of any formal analytical method. However, in most cases, an understanding of the root cause analytical methods is important to conducting an adequate inquiry and drawing correct conclusions.

**Table 1. Incident Types, Potential Consequences, and Recommended Root-Cause Analysis Methods for Undetected Cracking Incidents in Safety-of-Flight Structures**

| TYPE I | TYPE II | TYPE III |
|---|---|---|
| **Consequence:**<br><br>**Loss of or Significant Damage to Aircraft**<br><br>**Class A Mishap** | **Consequence:**<br><br>**Major Readiness or Economic Impact** | **Consequence:**<br><br>**Standard Repair Required** |
| **Criteria:**<br><br>$a_{miss} \geq a_{cr\text{-}miss}$<br><br>the undetected crack can grow to $a_{critical}$ in a period that is less than one inspection interval<br>(i.e. it can grow to $a_{critical}$ before the next inspection) | **Criteria:**<br><br>$a_{NDI} \leq a_{miss} < a_{cr\text{-}miss}$<br><br>the undetected crack cannot grow to $a_{critical}$ in a period that is less than one inspection interval<br>(i.e. it cannot grow to $a_{critical}$ before the next inspection) | **Criteria:**<br><br>$a_{miss} < a_{NDI}$<br><br>the undetected cannot grow to $a_{critical}$ in a period that is less than two inspection intervals<br>(i.e. it cannot grow to $a_{critical}$ before two inspections have been performed) |
| **Root Cause Analysis Methods:**<br><br>**Sequential Event and Causal Factor Analysis**<br><br>and<br><br>**Cause and Effect Analysis**<br><br>and<br><br>**Change Analysis**<br><br>and<br><br>**Human Performance Evaluation** | **Root Cause Analysis Methods:**<br><br>**Sequential Event and Causal Factor Analysis**<br><br>and<br><br>**Cause and Effect Analysis**<br><br>and<br><br>**Human Performance Evaluation**<br><br>with<br><br>**Change Analysis (if warranted)** | **Root Cause Analysis Methods:**<br><br>**Informal data gathering, analysis and reporting**<br><br>**with**<br><br>**Human Performance Evaluation (if warranted)** |

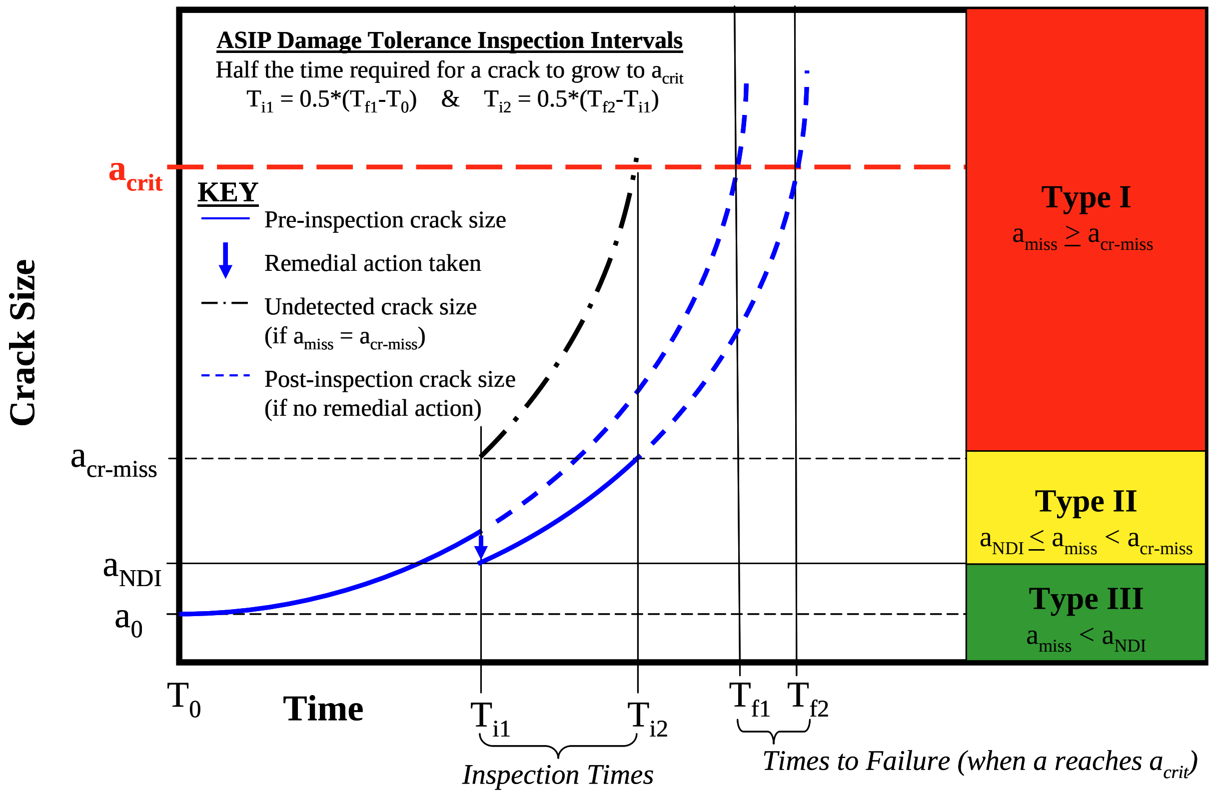



***Figure 1. Establishing the Type of an Undetected Crack Incident***

**Incident Report** - An incident report is a written evaluation of an incident that is prepared in sufficient detail to enable the reader to assess its significance, consequences, or implications and to evaluate actions being employed to correct the condition or to avoid recurrence.

**Reportable Incident** - An event or condition that meets the factors of a Type I or Type II incident.

**Root Cause** - The cause that, if corrected, would prevent recurrence of the incident under investigation and similar incidents. The root cause does not apply only to the incident being investigated, but has generic implications to a broad group of possible incidents. It is the most fundamental cause that can logically be identified and corrected. When a series of related or sequential causes can be identified, the series should be pursued until the fundamental, correctable (i.e. “root”) cause has been identified. It should be stressed that a root cause is a cause that is correctable or controllable. For example, adverse weather is not a root cause. However, a policy that governs how weather should affect NDI activities could be a root causes since it is controllable and correctable.

For example, the root-cause of an undetected crack in a safety-of-flight structure could be the lack of sufficient funds or schedule caused the engineering process to release inspection procedures to the field before sufficiently validating and verifying the procedures. This could have led to an incorrect application of an inspection technique by the inspector, which limited complete coverage of the inspection area, and which, ultimately, led to the lack of detection of an otherwise detectable defect.

For a second root cause example of the undetected crack in a safety-of-flight structure, suppose that the inspection was performed outside and that weather was found to be a factor in the lack of detection. A root cause could be that the leadership chain chose to expedite all maintenance procedures, regardless of their relation to safety, by requiring them to be performed without taking time to hangar the aircraft. A heavy war time OPTEMPO and poor weather were contributing causes, but only the leadership decision was truly controllable and correctable. Thus, the root cause was the leadership decision and was neither the weather conditions nor the pace of operations.

# 4. OVERVIEW OF INCIDENT INVESTIGATIONS

The objective of investigating and reporting the cause of incidents is to enable the identification of corrective actions that are adequate to prevent recurrence and thereby protects the safety of an aircraft structure, the crew, as well as the military and civilian population (i.e. plane crashes into school yard). Programs can then be improved and managed more efficiently and safely.

The investigation process is used to gain an understanding of the incident, its causes, and what corrective actions are necessary to prevent recurrence. The line of reasoning in the investigation process is:

- Outline what happened step-by-step.
- Begin with the incident by identifying the problem (condition, situation, or action that was not wanted and not planned).
- Determine what program element that was supposed to have prevented this incident (was it lacking or did it fail)?
- Investigate the reasons why this situation was permitted to exist.

This line of reasoning will explain why the incident was not prevented and what corrective actions will be most effective. This reasoning should be kept in mind during the entire root cause analysis process.

# 5. THE INVESTIGATION TEAM

Before an investigation can proceed, the investigating team must be formed. This team should only encompass the minimum number of subject matter experts required to effectively and efficiently accomplish the investigation. Care must be taken in selection of the team to ensure complete objectivity. For situations were the incident occurred within the depot, external expertise should be utilized to ensure investigation impartiality. For investigation of Type I and II incidents on U.S Air Force safety-of-flight aircraft structures, the following team composition is recommended.

Airframe ASIP Manager –Lead
Depot NDI Manager – Co-Lead
Depot NDI Production Representative
Depot Engineering Representative
Quality Representative
Union Representative
Airframe NDI technician
Additional Subject Matter Experts:

- Human Factors Analyst
- Root-Cause Analysis Facilitator
- Additional external structural and NDI experts as required to ensure investigation impartiality

# 6. PHASE I - COLLECTING

It is important to begin the Collecting phase of the root cause process immediately following the identification of an incident to minimize the loss of data and information.

The primary objective of the Collecting phase is to provide information that can be used to determine the direct, contributing and root causes so that effective corrective actions can be taken that will prevent recurrence. The information that should be collected consists of conditions before, during, and after the incident; personnel involved; actions taken; environmental factors; and any other relevant information. Considerations when determining what information is needed include:

- Activities related to the incident.
- Initial or recurring problems with procedures, equipment, personnel, software, etc., associated with the incident.
- Recent administrative program, procedure and/or equipment changes.
- Physical environment or circumstances such as facility temperature, humidity, lighting, noise levels, etc.
- Human factors variables such as inspector fatigue level, attitude, health, etc.

Some methods of gathering information include:

- Conducting interviews/collecting statements - Interviews must be fact-finding and not fault finding. Preparing questions before the interview is essential to ensure that all necessary information is obtained. The causal factor work sheets in Appendix F can be used as a tool to help gather information.

  Interviews should be conducted, preferably in person, with those people who are most familiar with the problem. Individual statements could be obtained if time or the number of personnel involved makes interviewing impractical. Interviews can be documented using any format desired by the interviewer.

  Although preparing for the interview is important, it should not delay prompt contact with participants and witnesses. The first interview may consist solely of hearing their narrative. A second, more-detailed interview can be arranged, if needed. The interviewer should always consider the interviewee's objectivity and frame of reference. Also, consider interviewing other personnel who have performed the job in the past.

- Conducting a "walk-through" recreation of events leading up to the incident – It may be useful to perform this in conjunction with interviews to help identify the series of events and roles of individuals before, during, and after the incident.
- Collecting physical evidence - Every effort should be made to preserve physical evidence such as failed components, inspection records, work orders and procedures. This should be done despite operational pressures to restore equipment to service. Establishing a quarantine area, or tagging and segregation of pieces and material, should be performed

for failed equipment or components. Physical evidence includes photographic documentation of the incident area from several views.

- Reviewing records - Review relevant documents or portions of documents as necessary and reference their potential use in support of the root cause analysis. Record appropriate dates and times associated with the incident on the documents reviewed. Examples of documents include the following:

  Operating logs
  Training records
  Correspondence
  Inspection/surveillance records
  Maintenance records
  Meeting minutes
  Procedures and instructions
  Work cards
  Vendor Manuals
  Drawings and specifications
  Equipment history records (repair, calibration, etc.)
  Failure analysis reports
  Design basis information
  Related quality control evaluation reports
  Work orders

- Acquiring related information - Some additional information that an evaluator should consider when analyzing the causes includes the following:

  - Laboratory tests, such as destructive/nondestructive failure analysis.

  - The physical layout of system, component, work area, including layout sketches and/or photographs.

  - Photographs of inspection access, physical position of inspector, instrument/display location, and probe placement during inspection.

  - Historical information of previous similar incidents if they have occurred at the same facility or facilities with similar inspection requirements.

  - Instrument, reference standards or sensor records including sensor performance and reference standard certifications, calibration records or correspondence that addressed system performance issues.

# 7. PHASE II – ANALYZING

## 7.1. Types of Root Cause Analysis Methods

Numerous analytical methods exit for conducting root cause analysis. However, for the purposes of this guide the following methods are recommended. Use the guidance of Table 1 to help select the analysis methods to use for a given incident type.

- Sequential Events and Causal Factor Analysis (Appendix A)
- Cause and Effect Analysis (Appendix B)
- Change Analysis (Appendix C)
- Human Performance Evaluation (Appendix D)

The extent to which these methods are used and the level of analytical effort spent on root cause analysis should be commensurate with the significance of the incident. A high-level of effort should be spent on Type I incidents related to safety-of-flight; an intermediate level should be spent on most unusual incidents (Type II); and a relatively low-level effort should be adequate for most off-normal incidents (Type III). In any case, the depth of analysis should be adequate to explain why the incident happened, determine how to prevent recurrence, and assign responsibility for corrective actions. An inordinate amount of effort to pursue the causal path is not expected if the significance of the incident is minor.

### 7.1.1. Sequential Events and Causal Factor Analysis

The Sequential Events and Causal Factor Analysis method is used to analyze multi-faceted problems or long, complex causal factor chains. This analysis method results in a chart that describes the time sequence of a series of events and/or actions and their surrounding conditions. The time sequence of actions or happenings is known as a "causal factor chain" or "chain of events". "Conditions" are things that shape the event outcomes; they range from physical conditions (such surfaces that are improperly prepared for inspections) to inspector attitudes and organizational safety culture. This method should be used to investigate all Type I and Type II incidents. Furthermore, this method must be used in conjunction with Cause and Effect Analysis to identify all possible causes (direct, root and contributing). Appendix A provides details for performing Events and Causal Factor Analysis.

### 7.1.2 Cause and Effect Analysis

The Cause and Effect Analysis method generates and sorts hypotheses about possible causes of a problem within a process by asking participants to list all of the possible causes and effects for the identified problem. This tool organizes a large amount of information by showing the links between the events and their potential or actual causes and provides a means of generating ideas (brainstorming) about why the problem is occurring and possible effects of that cause. The Cause and Effect Analysis method allows problem solvers to broaden their thinking and look at the overall picture of a problem. The resulting Cause and Effect Diagram can reflect either a) causes that block the way to the desired state or b) processes needed to reach the desired state. This method should be used to investigate all Type I and Type II incidents. Appendix B describes this method.

### 7.1.3. Change Analysis

Change Analysis investigates a problem by analyzing the deviation between what events are expected and what events actually occurred. The evaluator asks what occurred to make a task or activity result in a failure or problem when, previously, the task or activity was successfully completed. The Change Analysis method is primarily used to investigate complex problems or when previous similar actions or processes resulted in a positive outcome.

This method should be used in conjunction with the Sequential Events and Causal Factor Analysis method and the Cause & Effects Analysis method for the investigation of Type I incidents. It may also be used to augment investigations of Type II incidents. Appendix C describes this method.

### 7.1.4. Human Performance Evaluation

The Human Performance Evaluation method is used to identify factors that influence task performance. It is most frequently used for man-machine interface studies. Its focus is on examining operability and work environment, rather than on training operators to compensate for bad conditions. The Human Performance Evaluation method is extremely versatile and may be used to analyze most incidents since many conditions and situations leading to and ultimately result from some type of task performance problem. These problems may involve an analysis of planning, scheduling, task assignment, ergonomics/accessibility and instrumentation interfaces. Formal training in ergonomics and human factors is needed to perform adequate human performance evaluations, especially in man-machine interface situations. This method can be used to investigate any type of incident if warranted. Appendix D discusses this method.

### 7.2 Applying Root Cause Analysis Methods

Use the analytical methods described above by following three primary steps which are highlighted below. These steps are based upon the use of the most common analytical methods, the Sequential Events and Causal Factor Analysis method and the Cause & Effects Analysis method. Note, however, that if an initial evaluation of the incident indicates that the problem is very complex, that process changes have played a significant role, or that or issues with personnel or human factors are key contributing factors, then additional analysis methods should be brought to bear.

**Step 1. Determine the Causal Factor Chain (the Sequence of Events and Causal Factors).**

(a) The first step is to determine the sequence of events and/or actions that led up to the incident as well as their surrounding conditions. An effective way to document this is by using a sequential Events and Causal Factor Chart described in Appendix A. This type of chart provides a structure for investigators to organize and analyze the information gathered during the investigation and to identify gaps and deficiencies in knowledge as the investigation progresses. Preparation of an Events and Causal Factor Chart should begin as soon as the investigation starts. The chart is modified and updated as the relevant facts are uncovered. This chart should drive the data collection process by identifying data needs.

(b) Begin developing the Events and Causal Factor Chart by “working backwards” from the incident and identifying the events/actions and their associated conditions that immediately preceded the incident.

(c) Continue to work backwards and identify successively earlier events/actions and their associated conditions. Eventually, when this process is complete, you will be able to identify the root cause (the fundamental reason that, if corrected, will prevent recurrence of this and similar incidents).

**Step 2. Analyze the Causal Factor Chain**

The next step is to analyze the Causal Factor Chain. (If the Change Analysis and/or Human Performance Evaluation methods were used, these results may be useful in this step). For purposes of this guide, it is recommended that the Causal Factor Chain be analyzed using a Cause and Effects Chart otherwise known as a Fishbone or Tree Diagram. This charting method generates and sorts hypotheses about possible causes of an incident by asking participants to list all of the causes and effects related to the identified problem. Causes and effects identified by other analysis methods, including Sequence of Events and Causal Factor Analysis, Change Analysis and Human Performance Evaluation, must be incorporated in this step. The ultimate result is a graphical display, organized by major cause categories, of what is known and unknown and helps identify areas requiring additional investigation. Since all conditions are a result of prior actions, the diagram identifies what remaining questions to ask to follow the path to the source or root cause. Appendix B provides guidance on generating a Cause and Effects Chart.

**Step 3. Summarizing Findings, List Causal Factors**

(a) Once the causal factors have been sequenced using a Causal Factor Chain Chart and analyzed using a Cause & Effects Chart, they can be summarized and categorized. Causal factor should be categorized in two ways; in terms of their source, and in terms of their hierarchy with respect to the incident being investigated.

(b) Categorizing causal factors in terms of their source identifies general areas of a system, process, or component which will required focus attention during the development of corrective actions. "Cause Codes" such as those shown in Appendix E, should be used to categorize causal factors in terms of their source(s).

(c) Causal factors may also be categorized in terms of their hierarchy with respect to the incident being investigated. Causal factors may be identified as being contributing, direct, or root causes. Appendix F provides recommended worksheets to identify the hierarchical position of causal factors.

# 8. PHASE Ill - CORRECTING

In Phase II, the root cause analysis identified the causes to be corrected to avoid recurrence of an incident and, ultimately, to improve reliability and safety. In the Correcting phase (Phase III), effective corrective actions are selected and implemented based upon the results of the root cause analysis.

To begin, identify a potential corrective action for each cause; then ensure the viability of the potential corrective actions using the following questions. If the potential corrective actions are not viable, re-evaluate and identify alternate corrective actions.

1. Will the corrective action prevent recurrence?
2. Is the corrective action feasible?
3. Does the corrective action permit the primary objectives to be met and the mission to be accomplished?
4. If the corrective action introduces new risks, are those risks known and acceptable?
5. Do the corrective actions preserve the safety of other systems?
6. Were the immediate actions taken appropriate and effective in reducing risk of recurrence?
7. Are sufficient Policy Directives or Instructions in place?

A systems approach should be used in determining appropriate corrective actions. It should consider not only the impact they will have on preventing recurrence, but also the potential that the corrective actions may actually degrade safety. Also, the impact the corrective actions will have on other operations should be considered. The proposed corrective actions must be compatible with facility commitments and other obligations. In addition, those affected by or responsible for any part of the corrective actions, including management, should be involved in the process. Proposed corrective actions should be reviewed to ensure the above criteria have been met, and should be prioritized based on importance, scheduled (a change in priority or schedule should be approved by management), entered into a commitment tracking system, and implemented in a timely manner. A complete corrective action program should be based, not only on specific causes of incidents, but also on items such as lessons learned from other facilities, assessments, and personnel suggestions.

A successful corrective action program requires involving management at the appropriate level. Management must be willing to take responsibility and allocate adequate resources for corrective actions. Effective corrective action programs include the following:

- Management emphasis on the identification and correction of problems that can affect human and equipment performance, including assigning qualified personnel to effectively evaluate equipment/human performance problems, implementing corrective actions, and following up to verify corrective actions are effective.

- Developing administrative procedures that describe the process, identify resources, and assign responsibility.

- Developing a working environment that requires accountability for correction of impediments to error-free task performance and reliable equipment performance.

- Developing a working environment that encourages voluntary reporting of deficiencies, errors, or omissions.

- Sponsoring training programs for those individuals who are expected to conduct root-cause analyses.

- Training of personnel and managers to recognize and report incidents, including early identification of significant and generic problems.

- Developing programs to ensure prompt investigation following an incident or identification of declining trends in performance to determine root causes and corrective actions.

- Adopting a classification and trending system that identifies those factors that continue to cause problems with generic implications.

Additional specific questions and considerations in developing and implementing corrective actions include:

- Do the corrective actions address <u>all</u> the causes (especially the root cause(s))?

- What are the consequences of not implementing the corrective actions?

- What is the cost of implementing the corrective actions (capital costs, operations, and maintenance costs)?

- Will training be required as part of the implementation?

- In what time frame can the corrective actions reasonably be implemented?

- What resources are required for successful development of the corrective actions?

- What resources are required for successful implementation and continued effectiveness of the corrective actions?

- What impact will the development and implementation of the corrective actions have on other work groups?

- Is the implementation of the corrective actions measurable? (For example, "Revise step 6.2 of the technical order, to include diagrams, to clearly reflect the location requiring inspection" is measurable; "Ensure the actions of procedure step 6.2 are performed correctly in the future", is not measurable).

# 9. PHASE IV – INFORMING

Effectively preventing the recurrence of incidents requires the distribution of summary reports and lessons learned to all personnel who might benefit. Identification of report recipients depends upon the specific nature of the incident being investigated. However, at a minimum, personnel directly associated with the incident and those in their direct reporting chain should receive post-investigation reports. In addition, consideration should be given to directly sharing the details of root cause information with facilities and organizations that are engaged in similar work or where significant or long-standing problems may exist.

For Air Force investigations of structural inspection related incidents, it is recommended that, at a minimum, the following personnel and organizations be informed of the investigation findings and recommended corrective actions:

- Affected Inspection Facility Personnel
- Affected Inspection Facility Supervisor and Commander
- All Facilities Performing Similar Inspections
- Weapon System Manager
- Weapon System ASIP Manager
- Air Force NDI Office – AFRL/MLS-OL
- Major Command NDI Functional (MAJCOM/A4)
- Air Force Safety Center
- Air Force ASIP Manager – ASC/EN
- HQ AFMC/A4
- HQ AFMC/CV (Type I Incidents)

# 10. PHASE V – VERIFYING

In the Verifying phase, the effectiveness of corrective actions in resolving the root and contributing causes of the incident is evaluated. First, the corrective actions should be tracked to ensure that they have been properly implemented and are functioning as intended. Second, a structured review of corrective action tracking, normal process and change controls, and incident tracking should be conducted to ensure that past corrective actions have been effectively handled. The recurrence of the same or similar incidents must be identified and analyzed. If an incident recurs, the original incident should be re-evaluated to determine why corrective actions were ineffective. Also, the new incident should be investigated using the Change Analysis method. Process change controls should be evaluated to determine what improvements are needed to keep up with changing conditions. Early indications of deteriorating conditions can be obtained from tracking and trend analyses of incident information. Prompt corrective actions should be taken to reverse deteriorating conditions or to apply lessons learned.

# 11. REFERENCES

1. *Root Cause Analysis Guidance Document*, DOE-NE-STD-1004-92, US Department of Energy, February 1992

2. *Cause-and-Effect Diagram*, Basic Tools for Process Improvement.

3. *Events and Causal Factors Analysis*, SCIE-DOE-01-TRAC-14-95, August 1995, Technical Research and Analysis Center, Scientech Inc., Idaho Falls, Idaho

4. J.J. Rooney and L.N. Vanden Heuvel, *Root Cause Analysis for Beginners*, Quality Progress, July 2004, pgs 45-53

5. *Engine Problem Resolution: Root Cause and Failure Analysis*, Propulsion Center of Excellence Best Practice, PCOE BP 04-19, 17 February 2004.

# APPENDIX A

# SEQUENTIAL EVENTS AND CAUSAL FACTOR ANALYSIS

The Sequential Events and Causal Factor Analysis consist of two primary actions:

1) The Sequential Events Analysis
2) Events and Causal Factors Charting

## A1.0 SEQUENTIAL EVENTS ANALYSIS

Sequential Events (Walk-through) Analysis is a method in which personnel conduct a step-by-step reenactment of their actions for the observer without carrying out the actual function.

Objectives include:

- Determining how a task was really performed.

- Identifying problems in human-factors design, discrepancies in procedural steps, training, etc.

Preconditions are that participants must be the people who actually do the task.

Steps in Sequential Events and Causal Factor are as follows:

Step 1. Obtain preliminary information so you know what the person was doing when the problem or inappropriate action occurred.

Step 2. Decide on a task of interest.

Step 3. Obtain necessary background information:

- Obtain relevant procedures.
- Obtain system drawings if required, etc.
- Interview personnel who have performed the task (but not those who will be observed) to obtain understanding of how the task should be performed.

Step 4. Produce a guide outlining how the task will be performed. In the case of a maintenance action, the maintenance procedure or technical order, with key items underlined, is the easiest way of doing this. The guide should indicate steps in performing the task and key controls and displays so that:

- You will know what to identify.
- You will be able to record actions more easily.

Step 5. Thoroughly familiarize yourself with the guide and decide exactly what information you are going to record and how you will record it.

You may want to check off each step and controls or displays used as they occur. Discrepancies and problems may be noted in the margin or in a space provided for comments, adjacent to the step.

Step 6. Select personnel who normally perform the task. If the task is performed by multiple individuals, the individuals should play the same role they fulfill when performing the task. Observe personnel walking through the task and record their actions and use of displays and controls. Note discrepancies and problem areas.

Step 7. You should observe the task as it is normally performed; however, if necessary, you may stop the task to gain full understanding of all steps. Conducting the task as closely to the conditions that existed when the event occurred will provide the best understanding of the event causal factors.

Step 8. Summarize and consolidate any problem areas noted. Identify probable contributors to the event.

Step 9. Generate a Events and Causal Factors Chart to assist in a logical assessment of the findings. From the Events and Causal Factors Chart identify the most probable causes. Guidance for Events and Causal Factor Charting are provided in the following section 2.0.

## A2.0 EVENTS AND CAUSAL FACTOR CHARTING

(Adapted from the DOE publication SCIE-DOE-01-TRAC-14-95, *Events and Causal Factor Analysis*)

### A2.1 What is an Events and Causal Factor Chart?

The Events and Causal Factors (ECF) chart depicts the necessary and sufficient events and causal factors for an incident in a logical sequence. It can be used not only to analyze the incident and evaluate the evidence during investigation, but also can help validate the accuracy of pre-incident systems analyses.

The primary purpose of the investigation is to determine what happened and why it happened in order to prevent similar incidents and to improve the safety and efficiency of future operations. When serious incidents occur, they are often symptomatic of systemic deficiencies which also impair performance and production. When the incident is used as a window through which to view the existing management system, these deficiencies are revealed and benefits are derived which go far beyond correction of the immediate causes of the incident. The emphasis, then, should be placed on discovering all cause-effect relationships from which practical corrective actions can be derived to improve total performance. **The intent of the investigation, then, is not to place blame, but rather to determine how responsibilities can be clarified and how loss-producing errors can be reduced and controlled**. Accurate ECF charts can help satisfy these general purposes by:

- providing a cause-oriented explanation of the accident;
- providing a basis for beneficial changes to prevent future occurrences and operational errors;
- helping delineate areas of responsibility;
- helping assure objectivity in the conduct of the investigation;
- organizing quantitative data (e.g., time, velocity, temperature, etc.) Related to events and conditions;
- acting as an operational training tool;
- providing an effective aid to future systems design.

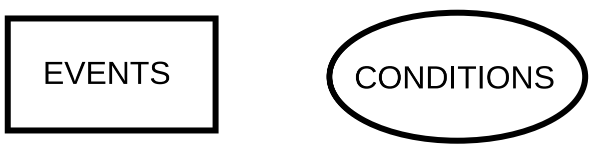
More specifically, an ECF chart:

- aids in developing evidence, in detecting all causal factors through sequence development, and in determining the need for in-depth analysis;
- clarifies reasoning;
- illustrates multiple causes. As previously stated, safety incidents rarely have a single "cause". Charting helps illustrate the multiple causal factors involved in the accident sequence, as well as the relationship of proximate, remote, direct, and contributory causes;
- visually portrays the interactions and relationships of all involved organizations and individuals; illustrates the chronology of events showing relative sequence in time;
- provides flexibility in interpretation and summarization of collected data;
- conveniently communicates empirical and derived facts in a logical and orderly manner;
- links specific incident factors to organizational and management control factors.

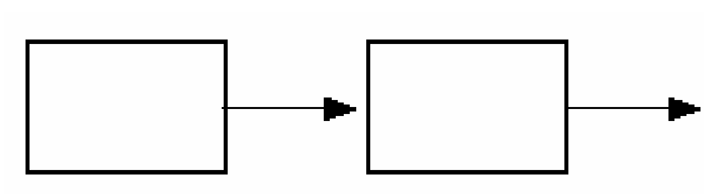
Sections A2.2 and A2.3 provide a set of conventions and criteria to be used in ECF charting. These conventions are intended to improve comparability and consistency in incident reporting and to assist the communication of investigation findings. These conventions are intended to be as simple as possible while preserving the effectiveness of ECF charts. It is further intended that investigators be provided with helpful guidelines without inhibiting their use of this tool by imposing an overly complex set of rules. In section A3.0, more general guidelines are given for the performance of the Sequential Events and Causal Factor Analysis method. An example Events and Causal Factor Charting is provided in section A3.1

**A2.2 Conventions for Events and Causal Factors Charts**

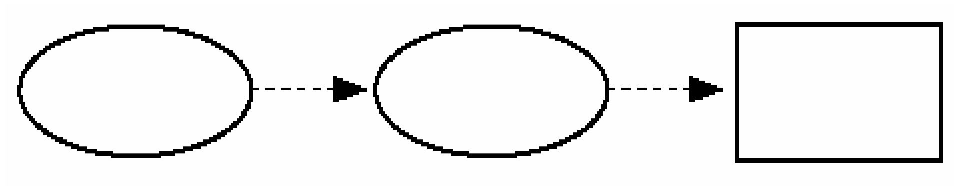
(a) Events should be enclosed in rectangles, and conditions in ovals.



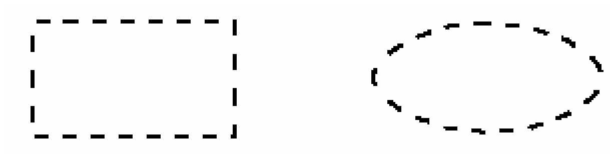

(b) Events should be connected by solid arrows.



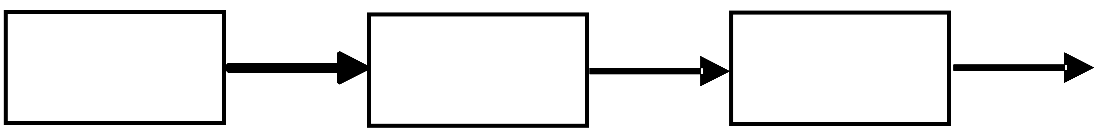
(c) Conditions should be connected to each other and to events by dashed arrows.



(d) Each event and condition should either be based upon valid factual evidence or be clearly indicated as presumptive by dashed line rectangles and ovals.

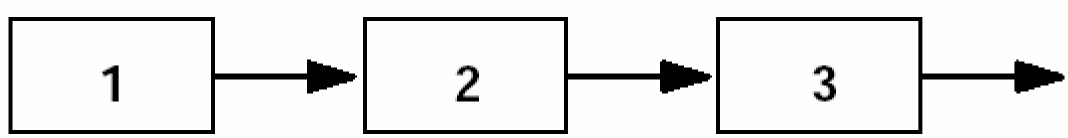


(e) The primary sequence of events should be depicted in a straight horizontal line (or lines in confluent or branching primary chains) with events joined by bold printed connecting arrows.



(f) Secondary event sequences, contributing factors, and systemic factors should be depicted on horizontal lines at different levels above or below the primary sequence.

(g) Events should be arranged chronologically from left to right.




(h) Events should track in logical progression from the beginning to the end of the event sequence and should include all pertinent incidents. This necessitates that the beginning and the end be defined for each incident sequence. Analysts frequently use the incident as the key event and proceed from it in both directions to reconstruct the pre-incident and post-incident ECF sequences.

**A2.3 Suggested Criteria for Event Descriptions and Conditions**

(a) Each event should describe an incident or happening and not a condition, state, circumstance, issue, conclusion, or result; i.e., “Aircraft was grounded due to large crack in wing caused a fuel leak”.

(b) Each event should be described by a short sentence with one subject and one active verb; i.e., “technician performed visual inspection of landing gear trunnion”, not “technician wiped down the landing gear trunnion with solvent and then performed visual inspection”.

(c) Each event should be precisely described; i.e., “the technician adjusted the inspection frequency to 20kHz ‘on’ position”, not “the technician selected the inspection frequency”.

(d) Each event should describe a single, discrete incident; i.e., “flap-track liberated from airframe”, not “flap-track liberated from aircraft and FODed engine”.

(e) Each event should be quantified when possible; i.e., “plane descended 350 feet”, not “plane lost altitude.”

(f) Each event should be derived directly from the event (or events in the case of a branched chain) and conditions preceding it; i.e., “inspector identified inspection location by “feel” using right hand” is preceded by “inspector crawled into fuel cell to gain access” which is preceded by “the crew chief removed fuel cell access panel IAW TO” - each event deriving logically from the one preceding it. When this is not the case, it usually indicates that one or more steps in the sequence have been left out.

(g) Conditions differ from events insofar as they (a) describe states or circumstances rather than happenings or incidents and (b) are passive rather than active. As far as practical, conditions should be precisely described, quantified when possible, posted with time and date when possible, and be derived directly from the conditions immediately preceding them.

**A3.0 Guidelines for Practical Application**

The experience of many people participating in numerous accident investigations has led to the identification of seven key elements in the practical application of Sequential Events and Causal Factor Analysis to achieve high quality accident investigations.

(a) Begin early, as soon as you start to accumulate factual information on events and conditions related to the incident, begin construction of a “working chart” of events and causal factors. It is often helpful also to rough out a fault tree of the incident to establish how the accident could have happened. This can prevent false starts and ‘wild goose chases” but must be done with caution so that you don’t lock yourself into a preconceived model of the incident.

(b) Remember to keep the proper perspective in applying these guidelines; they are intended to guide you in the simple application of a valuable investigative tool. They are not exact rules that must be applied without question or reason. If you have a truly unique situation and feel that you must deviate from the guidelines for clarity and simplicity, do it. Analytical techniques should be servants not masters.

(c) Proceed logically with available data. Events and causal factors usually do not emerge during the investigation in the sequential order in which they occurred. Initially, there may be many holes and deficiencies in the chart. Efforts to fill these holes and get accurate tracking of the event sequences and their derivation from contributing conditions will lead to deeper probing by investigators that will uncover the true facts involved. In proceeding logically, using available information to direct the search for more, it is usually easiest to use the incident as the starting point and reconstruct the pre-accident and post-accident sequences from that vantage point.

(d) Use an easily updated format. As additional facts are discovered and analyses of those facts further identify causal factors, the working chart will need to be updated. Unless a format is selected which displays the emerging information in an easily modified form, construction of the chart can be very repetitious and time-consuming. Successive redrafts of the ECF chart on large sheets of paper have been done; magnetic display boards or chalkboards have been used; but the technique that has consistently proven most effective and most easily updated is use of “post-it” notes on which brief event or condition statements are written. A single event or condition is written on each note. The notes are then stuck to a wall or a large roll of heavy paper in the sequence of events as then understood. As more information is revealed, notes can be rearranged, added, or deleted to produce a more complete and accurate version of the working chart. Once the note-based working chart has been finalized, the ECF chart can be drawn for inclusion in the investigation report.

(e) Select the appropriate level of detail and sequence length for the ECF chart. The incident, itself, and the depth of investigation specified by the investigation commissioning authority will often suggest the amount of detail desired.

(f) Make a short executive summary chart when necessary. The ECF working chart will contain much detail so it can be of greatest value in shaping and directing the investigation. In general, significantly less detail is required in the ECF chart presented in the investigation report, because the primary purpose is to provide a concise and easy-to-follow orientation to the accident sequence for the report reader. When a detailed ECF chart is felt to be necessary to show appropriate relationships in the analysis section of an appendix of the report, an executive summary chart of only one or two pages should be prepared and included in the report to meet the above stated purpose.

### A3.1 Events & Causal Factors Chart Example

Application of the suggested format and event description criteria for constructing a typical ECF chart of a simple inspection incident are illustrated in the following example.

<u>Incident Description</u>

A 30 day time compliance technical order (TCTO) was released requiring the eddy current inspection of the wing flap track on a dual engine US Air Force aircraft. The TCTO tech data was successfully validated by depot NDI and structural engineering prior to TCTO release. The TCTO was scheduled to be accomplished on 21 December 2004, on A/C 90-678 prior to a scheduled 7:00 AM training mission. The aircraft was grounded pending successful performance of the TCTO. The inspector assigned to the inspection task was late arriving to work. No other inspection personnel were available at the time due to holiday vacations. To expedite flight preparations, the crew chief rolled the aircraft out of the hangar at 8:00 AM to perform an engine check. At 9:35 AM the inspector arrives at work and is assigned the task by his supervisor. At 10:00 AM the inspector arrives at the aircraft and performs the inspection. The outdoor ambient temperature was 25ºF with light winds at the time of the inspection. The indoor ambient condition where the inspection equipment was stored was 65ºF. On 27 February 2005, A/C 90-678, experienced an in-flight failure of the left engine, declared an in-flight emergency and landed safely at a local municipal airport.

A subsequent failure analysis revealed that the left-wing flap-track failed, resulting in the in-flight liberation of a mounting bracket. The bracket was ingested by the engine, resulting in FOD damage and engine failure. Laboratory analysis indicted the flap track failed due to fatigue. Analysis also indicates that the crack was between $a_{NDI}$ and < $a_{critical}$ ($a_{NDI}$ but < $a_{critical}$) was present during the previous inspection.

The resulting investigation revealed that the inspector apparently elected to ignore TCTO requirements for aircraft hangaring during inspection. Furthermore the inspector did not allow inspection equipment, probes and reference standard to reach ambient conditions prior to beginning the inspection. Failure to due so resulted in excessive instrument drift and misinterpretation of inspection results. The causal factors for the undetected crack in the flap were a) failure of the inspector to follow technical data and b) failure of management to ensure sufficient personnel resources to address mission needs.

Discussion

Figure A1 is the ECF chart of this incident. Note that the events are in chronological order, that each follows logically from the one preceding and that the dates are indicated where known. Events are enclosed in rectangles and the conditions in ovals. Event statements are characterized by single subjects and active verbs. Primary events are connected by bold solid lines, other events by solid lines, and conditions by dashed lines. Presumptive information (i.e., the inference is clear but the evidence is lacking) is shown in ovals and rectangles drawn in dashed lines.

Note: The ECF technique can provide a clear illustration of the timeline of conditions and events, as well as help to identify significant causal factors. However, use of this technique alone may result in the failure to identify other significant causal factors which may be uncovered with application of additional RCA methods.

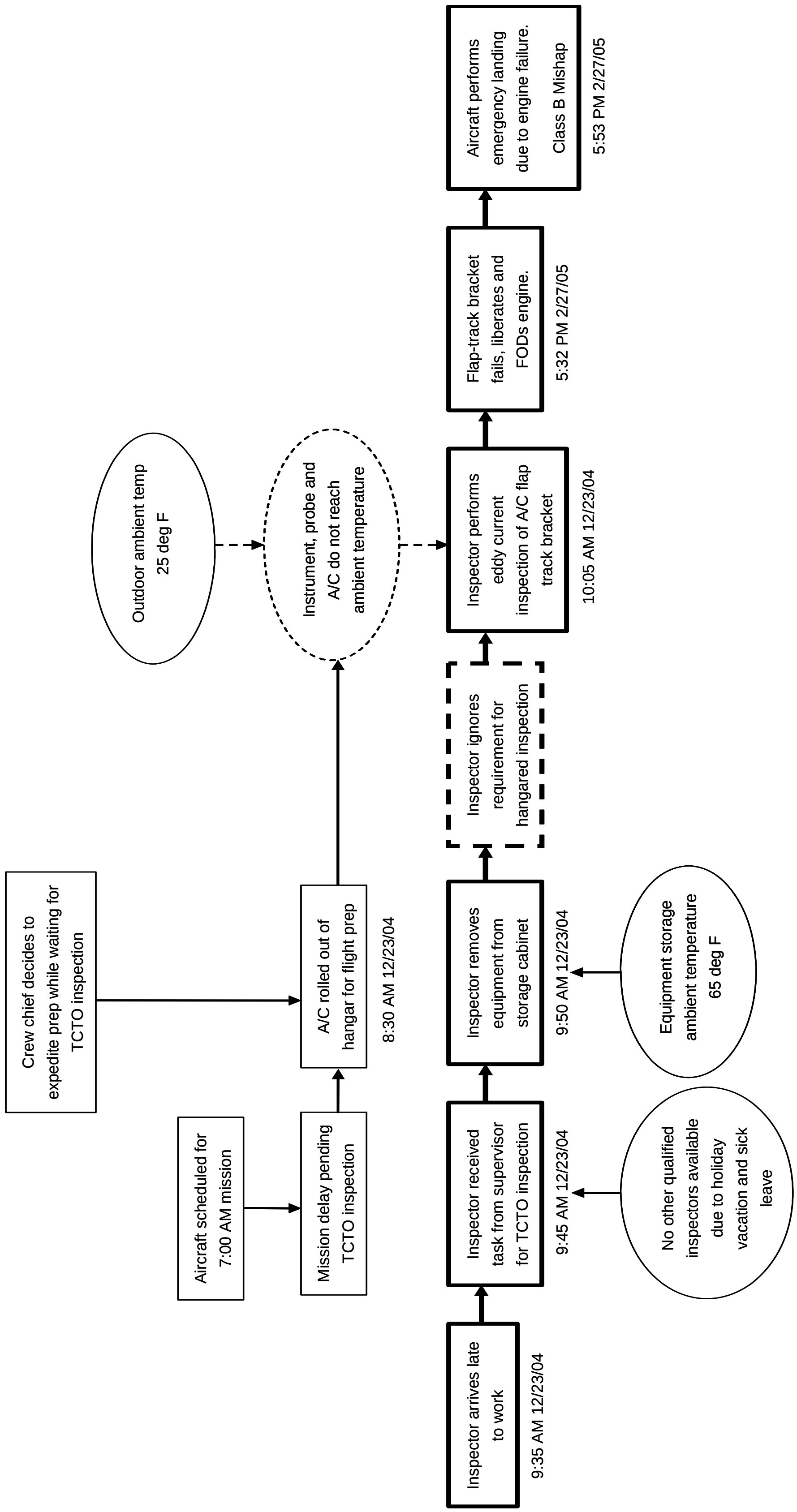



***Figure A1. Events & Causal Factors Chart Example***

# APPENDIX B

## CAUSE AND EFFECT ANALYSIS

(Adapted from *Basic Tools for Process Improvement*)

Cause and Effect Analysis is a root cause analysis method generates and sorts hypotheses about possible causes by listing all possible causes and effects.

Once the data gathering and initial analysis is complete then the possible causes and effects can be graphically organized. A Cause and Effect Diagram is a tool that helps quickly identify, sort and display possible causes of a specific problem. It graphically illustrates the relationships between a given outcome and all the factors that influence the outcome. This type of diagram is sometimes called an “Ishikawa diagram” because it was invented by Kaoru Ishikawa, or a “Fishbone Diagram” because of the way it looks. This diagram should incorporate the resulting findings from the Sequential Event and Causal Factor Analysis as well as the Change Analysis and Human Performance Evaluations if performed.

***When should you use a Cause and Effect Diagram?***

A Cause and Effect Diagram can help when you need to:

- Identify the possible root causes, the basic reasons, for a specific effect, problem or condition.
- Sort out and relate some of the interactions among the factors affecting a particular process or effect.
- Analyze existing problems so that corrective action can be taken.

***Why Use a Cause and Effect Diagram?***

A Cause and Effect Diagram is a tool useful for identifying and organizing the known or possible causes. The structure provided by the diagram helps the team members think systematically. Constructing a Cause-and-Effect Diagram will help in:

- Determining the root cause of a problem or quality characteristic using a structured approach.
- Encouraging group participation and utilizes group knowledge of the process.
- Using an orderly, easy-to-read format to diagram cause-and-effect relationships.
- Indicating possible causes of variations in a process.
- Increasing knowledge of the process by helping everyone learn more about the factors at work and how they relate.
- Quickly eliminating non-causal issues.
- Identifying areas where data should be collected for further study.

**<u>How to Develop a Cause-and-Effect Diagram</u>**

When you develop a Cause-and-Effect Diagram, you are constructing a structured, pictorial display of a list of causes organized to show their relationship to a specific effect. The data will be analyzed to identify the causal factors, summarizing the findings, and categorizing the findings by the cause categories. The major cause categories are:

- Equipment/Material Deficiency
- Procedure Deficiency
- Personnel Deficiency
- Design/Engineering Deficiency (includes incorrect assumptions)
- Training Deficiency
- Management/Organizational Deficiency
- External Phenomenon

These categories have been selected with the intent to address all problems that could arise while conducting inspection and maintenance operations. The first three categories are necessary to perform any task (equipment, procedures and personnel). Design and training determine the quality and effectiveness of equipment and personnel. These elements must be managed; therefore, management is also a necessary element as it provides the priorities and resources to support requirements. Whenever there is an incident, one of these six program elements was inadequate to prevent the incident. (An external factor beyond operational control serves as a seventh cause category). These causal factors can be associated in a logical causal factor chain as shown in Figure B1. (Note that a direct, contributing, or root cause can occur any place in the causal factor chain; that is, a root cause can be an operator error while a management problem can be a direct cause, depending on the nature of the incident). These seven cause categories are subdivided into a total of 32 subcategory cause code. The direct cause, contributing causes, and root cause are all selected from these subcategories (see Appendix E).

The steps for constructing and analyzing a Cause-and-Effect Diagram are as follows:

**Step 1** – Identify and clearly define the outcome or EFFECT to be analyzed.

- Decide on the effect to be examined. Effects are stated as a fault conditions or the result or outcome of a fault condition.
- Use Operational Definitions. Develop an Operational Definition of the effect to ensure that it is clearly understood.

**Step 2** – Draw the SPLINE and create the EFFECT box.

- Draw a horizontal arrow pointing to the right. This is the spline.
- To the right of the arrow, write a brief description of the effect.

The following example will diagram the causes relating to a fatigue crack missed during an inspection of an aircraft flap track**.** Therefore, the EFFECT is Missed Fatigue Crack in Flap Track (See Figure B1)

- Draw a box around the description of the effect.

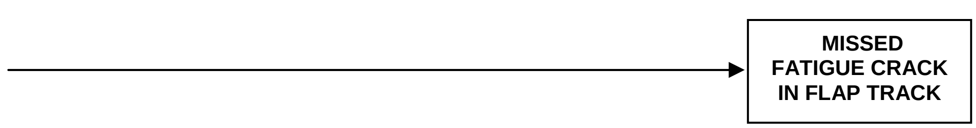



***Figure B1. Spline Drawn to the Effect***

**Step 3** – Identify the main CAUSES contributing to the effect being studied. These are the labels for the major branches of your diagram and become categories under which to list the main causes related to those categories.

- Establish the main causes, or categories, under which other possible causes will be listed. You should use category labels that make sense for the diagram you are creating. It is recommended that the cause categories defined in Appendix E be used. These categories are as follows:

    - Equipment/Materials
    - Procedures
    - Personnel
    - Design/Engineering
    - Training
    - Management/Organization
    - External Phenomenon

- Write the main categories your team has selected to the left of the effect box, some above the spline and some below it.

- Draw a box around each category label and use a diagonal line to form a branch connecting the box to the spline (See Figure B2).

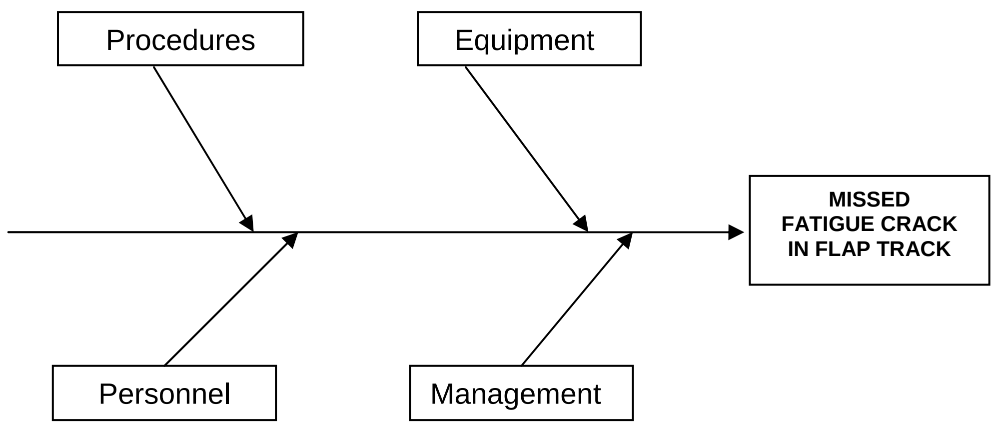



***Figure B2. Main Cause Categories Connected by a Spline to the Effect***

**Step 4** – For each major branch, identify other specific factors which may be the CAUSES of the EFFECT.

- Identify as many causes or factors as possible and attach them as sub-branches of the major branches.

  EXAMPLE: The possible CAUSEs for the Missed Fatigue Crack in Flap Track are listed under the appropriate categories in Figure B3.

- Fill in detail for each cause.  If a minor cause applies to more than one major cause, list it under both.

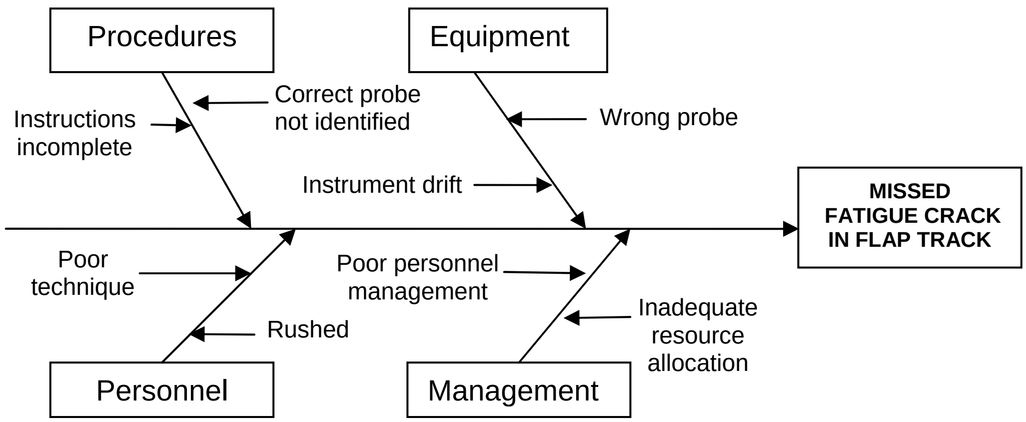



***Figure B3.   Cause and Effects Diagram - First Level Causes***

**Step 5** – Identify increasingly more detailed levels of cause and continue organizing them under related causes or categories.  You can do this by asking a series of questions.

EXAMPLE:  Use a series of why questions to fill in the detailed levels for one of the causes listed under each of the main categories.

PROCEDURES

Q:  Why were the INSTRUCTIONS INCOMPLETE?
A:  Poor definition of inspection zone.
  Q:  Why was the inspection zone poorly defined?
  A:  Procedures not validated.

EQUIPMENT

Q:  Why was the WRONG PROBE used?
A:  Instructions Ignored.
  Q: Why were the instructions ignored?
  A:  Inspector inexperience.
  A:  Inspector unprepared/pressured.
A:  Correct probe failed and not available.
  Q:  Why was a replacement probe not available?
  A:  No $ for replacement.

PERSONNEL

Q:  Why was the inspector RUSHED?
A:  Always late to work.
A:  Command pressure - Wing Commander angry due to mission delay

Figure B4 shows how the diagram looks when all the contributing causes that were identified by the series of why questions have been filled in.  As you can see, there may be many levels of causes contributing to the effect.

NOTE: You may need to break the diagram into smaller diagrams if one branch has too many sub-branches. Any main cause can be reworded into an effect.

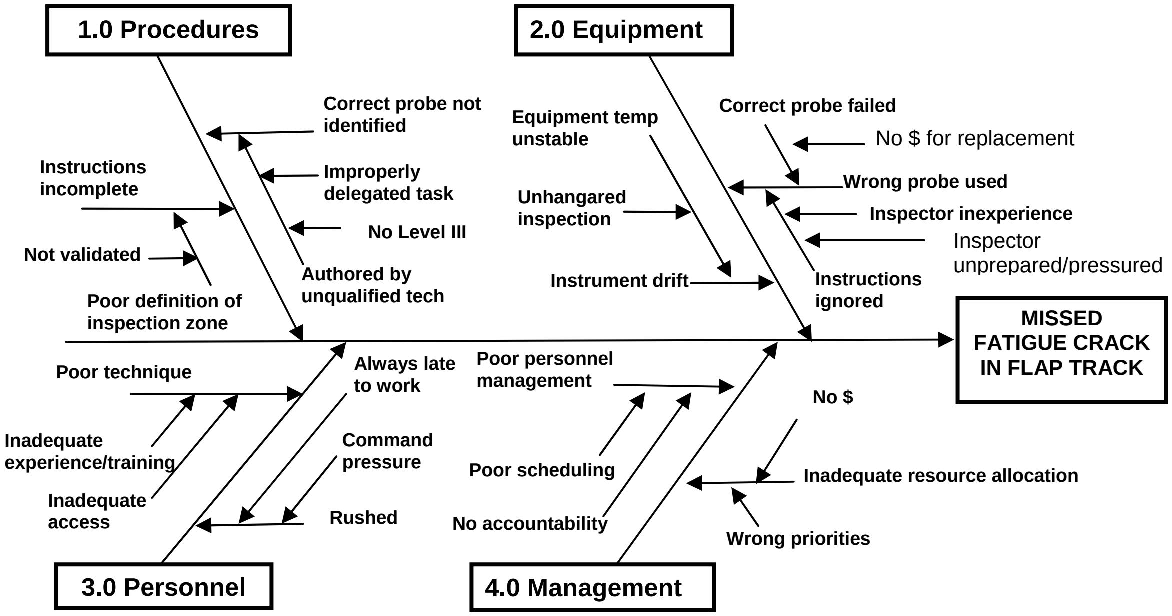



***Figure B4. Cause and Effects Diagram – With Multiple Contributing Causes***

**Step 6** – Assign a numeric code for each of the causes and minor causes. One approach is shown in the following example:

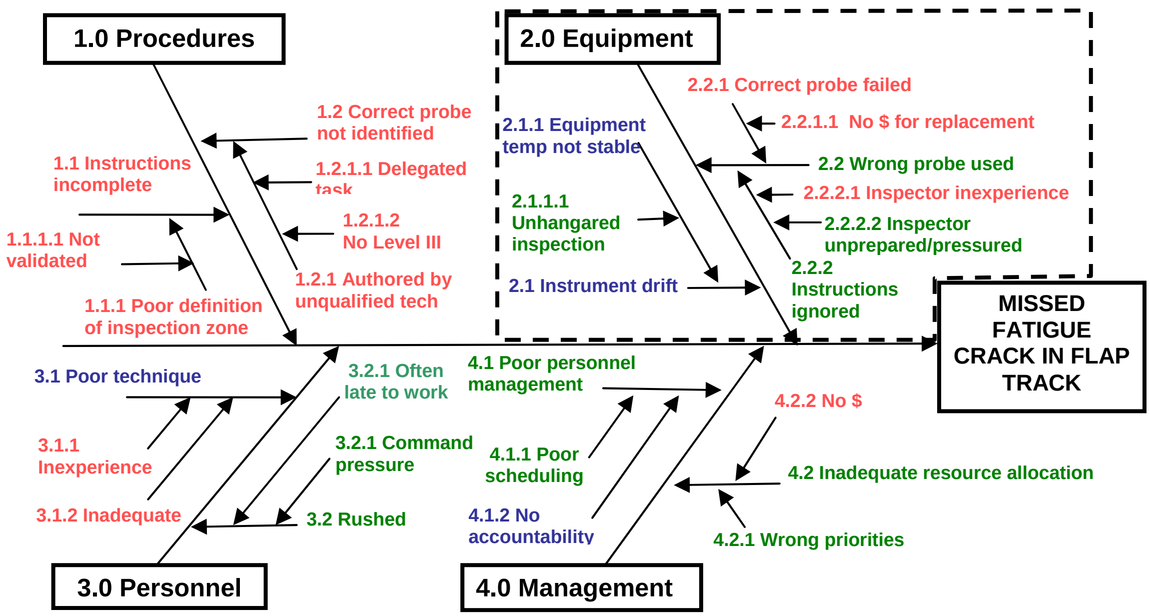
EXAMPLE: See Figure B5. Note: Cause level expanded further

- 3.0 EQUIPMENT
  - 3.1 Instrument drift
    - 3.1.1 Equipment temp unstable
      - 3.1.1.1Unhangared Inspection
        - 3.1.1.1.1 Inadequate procedures
        - 3.1.1.1.2 Instructions ignored
  - 3.2 Wrong Probe Used
    - 3.2.1 Correct probe failed
      - 3.2.1.1 No $ for replacement
    - 3.2.2 Instructions ignored
      - 3.2.2.1 Inadequate experience/training
      - 3.2.2.2 Inspector unprepared/pressured

On a spreadsheet, for each cause, list the major cause and each minor cause and two ways you know it to be true. If only one way is known or not firm, all possible causes should be evaluated as potential causes, and the bases for rejected and accepted causes should be stated.

All possible minor causes must be validated as either true or untrue. If sufficient evidence indicates the minor cause(s) are <u>not</u> true then they should be eliminated as possible contributors. Color coding the Cause and Effect Diagram and supporting spreadsheet may be helpful.

**RED** – PROVEN UNTRUE
**GREEN** – PROVEN TRUE
**BLUE** - FURTHER ANALYSIS REQUIRED




| 2.0 Equipment | Supporting or Refuting Evidence |
|---|---|
| 2.1 Instrument Drift | • During interview inspector reported unexplained instrument draft |
| 2.1.1 Equipment temp not stable | • Recreation of inspection ambient conditions did not result in level of drift reported by inspector - further test required |
| 2.1.1.1 Unhangered Inspection | • Interview with inspector indicated inspection was conducted on flightline (25º F).<br>• Inspector indicated he did not follow T.O. Chapter 1 requirements for allow instrument/standard temp to reach ambient. |
| 2.2 Wrong probe used | • Investigation/interview indicated unshielded probe was used. Shielded probe required when inspection around ferromagnetic bushings. |
| 2.2.1 Correct probe failed | • Correct shielded probe found in NDI shop. |
| 2.2.1.1 No $ for replacement | • Sufficient funds available at the time. |
| 2.2.2 Instructions ignored | • Inspector did not select correct probe |
| 2.2.2.1 Inspector inexperience | • Inspector task certified by supervisor to complete inspection<br>• Inspector successfully identified cracks in similar inspection on three previous occasions. |
| 2.2.2.2 Inspector unprepared/pressured | • Interviews with inspector and management identified concerns with tardiness and poor moral affecting performance. Excessive command pressure indicated. |

***Figure B5. Example of color coded and numerically ordered Cause and Effect Diagram and supporting spreadsheet. Only the Equipment breakdown is shown in the supporting spreadsheet.***

**Step 7** – Analyze the diagram. Analysis helps identify causes that warrant further investigation. Since Cause-and-Effect Diagrams identify only possible causes, you may want to use a Pareto Chart to help determine the cause to focus on first.

- Look at the "balance" of your diagram, checking for comparable levels of detail for most of the categories.
  - A thick cluster of items in one area may indicate a need for further study.
  - A main category having only a few specific causes may indicate a need for further identification of causes.
  - If several major branches have only a few sub-branches, you may need to combine them under one category.
- Look for causes that appear repeatedly. These may represent root causes.
- Look for what you can measure in each cause so you can quantify the effects of any changes you make.
- Most importantly, clearly identify the causes you can take action on.

When this process gets to the point where a cause can be corrected to prevent recurrence in a way that allows meeting your objectives and is within your control, you have found the root cause or causes.

***Alternate Approach for Charting Cause and Effect***

An alternate approach for graphically depicting the same information presented in the Fishbone Diagram is illustrated in FigureB6. The chart illustrates an inverted "tree" diagram which may be useful for clearly briefing the results of the RCA to management.

Through examination of Figures B5 and B6 one can quickly identify areas of concern and isolate the most probable contributing, direct and root causes. For example, the PROCEDURE branch is completely red and therefore cannot be the location of the contributing or root causes. However, the other three categories (EQUIPMENT, PERSONNEL and MANAGEMENT) contain "greens" which are candidate locations for contributing and root causes.

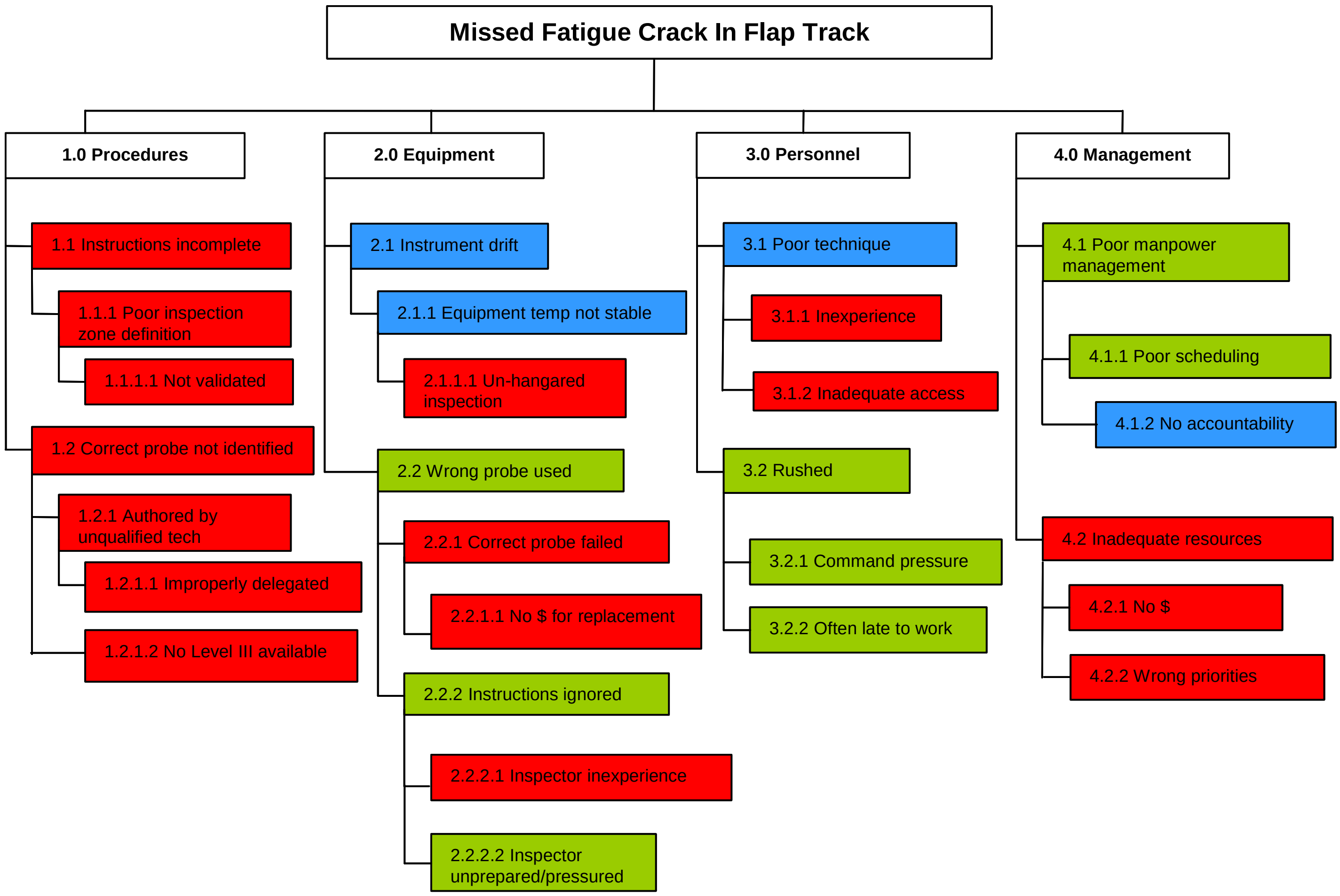



***Figure B6. Example of Cause and Effect Tree Diagram***

# APPENDIX C

# CHANGE ANALYSIS

Change Analysis looks at a problem by analyzing the deviation between what is expected and what actually happened. The evaluator essentially asks what differences occurred to make the outcome of this task or activity different from all the other times this task or activity was successfully completed.

This technique consists of asking the questions: What? When? Where? Who? How? Answering these questions should provide direction toward answering the root cause determination question: Why?

Primary and secondary questions included within each category will provide the prompting necessary to thoroughly answer the overall question. Some of the questions will not be applicable to any given condition. Some amount of redundancy exists in the questions to ensure that all items are addressed.

Several key elements include the following:

- Consider the event containing the undesirable consequences.
- Consider a comparable activity that did not have the undesirable consequences.
- Compare the condition containing the undesirable consequences with the reference activity.
- Set down all known differences whether they appear to be relevant or not.
- Analyze the differences for their effects in producing the undesirable consequences. This must be done with careful attention to detail, ensuring that obscure and indirect relationships are identified (e.g., a change in color or finish may change the heat transfer parameters and consequently affect system temperature).
- Integrate information into the investigative process relevant to the causes of, or the contributors to, the undesirable consequences.

Change Analysis is a good technique to use whenever the causes of the condition are obscure, you do not know where to start, or you suspect a change may have contributed to the condition.

Not recognizing the compounding of change (e.g., a change made five years previously combined with a change made recently) is a potential shortcoming of Change Analysis. Not recognizing the introduction of gradual change as compared with immediate change also is possible.

This technique may be adequate to determine the root cause of a relatively simple condition. In general, though, it is not thorough enough to determine all the causes of more complex conditions.

Figure C-1 shows the six steps involved in Change Analysis. Figure C-2 is the Change Analysis worksheet.

The following questions help identify information required on the worksheet:

**WHAT?**

- What is the inspection?
- What occurred to require the inspection?
- What occurred prior to the inspection?
    - Was the inspection area/surface prepared properly?
- What occurred following the inspection?
- What activity was in progress when the inspection was being performed?
- What activity was in progress when the missed crack was identified?
    - Operational evolution in the work space?
        - Power increase/decrease?
        - Environmental change (temperature, precipitation, wind, noise)?
        - Starting/stopping inspection or inspection interruption?
        - Inspection access?
        - Inspector position during inspection?
    - Operational evolution outside the work space?
        - Removing inspection equipment from service?
        - Returning inspection equipment to service?
    - Maintenance activity just prior or at time of inspection?
        - Corrective maintenance?
        - Modification or configuration change?
        - Troubleshooting?
    - Training activity?
- What inspection equipment, sensors and standards were involved when the defect condition was missed by the suspect inspection?
- What was the operational condition of the equipment, standards and sensors?
    - What is the equipment's function?
    - How does it function?
    - Were operational procedures available?
    - Was the equipment operating properly?
    - Was the procedure followed properly?
    - What maintenance or calibration has been performed on the inspection equipment?
    - What modifications have been made to the equipment, standards or sensors?
- What inspection equipment, sensors and standards were involved when the defect condition was identified?
    - What was the operational condition of the equipment, standards and sensors?
    - What is the equipment's function?
    - How does it function?
    - What operational procedures were available?
    - Was the equipment operated properly?
    - What maintenance or calibration has been performed on the inspection equipment?
    - What modifications have been made to the equipment, standards or sensors?
        - Were the modifications authorized?

**WHEN?**

- When did incident (failure to detect defect) occur?
- When was the defect identified?
- What was the facility’s status at the time during the incident (failed inspection)?
- What was the facility’s status at the time when the defect was identified?
- What effects did the time of day have on the? Did it affect:
    - Information availability?
    - Personnel availability?
    - Ambient lighting?
    - Ambient temperature?
- Did the incident involve shift-work personnel? If so:
    - What type of shift rotation was in use?
    - Where in the rotation were the personnel?
- For how many continuous hours had any involved personnel been working?
- Did the incident occur at the beginning, middle or end of the work week?
- Did the incident occur immediately before or after a holiday?

**WHERE?**

- Where did the incident (failed inspection) occur?
- Where was the defect detected?
- What were the physical conditions in the area?
- Where was the incident identified?
- Was location a factor in causing the condition?
    - Human factor?
        - Lighting?
        - Noise?
        - Temperature?
        - Equipment labeling?
        - Personal protective equipment required in the area?
        - Accessibility?
        - Indication availability?
        - Other activities in the area?
        - What position is required to perform tasks in the area?
    - Equipment factor?
        - Humidity?
        - Temperature?
        - Cleanliness?

**HOW?**

- Was the incident (failed inspection) a result of, or caused, by an inappropriate action?
    - An omitted action?
    - An extraneous action?
    - An action performed out of sequence?
    - An action performed to a too small of a degree? To a too large of a degree?
- Were the procedures used a factor in the incident (failed inspection)?
    - Was there an applicable procedure?
    - Was the correct procedure used?
    - Was the procedure followed?
        - Followed in sequence?
        - Followed "blindly"--without thought?

- Was the procedure:
    - Legible?
    - Misleading?
    - Confusing?
    - An approved, current revision?
    - Adequate to do the task?
    - In compliance with other regulations?
- Did the procedure:
    - Have sufficient detail?
    - Have sufficient warnings and precautions?
    - Adequately identify techniques and components?
    - Have steps in the proper sequence?
    - Require adequate work review?
    - Make inaccurate assumptions?

**WHO?**

- Which personnel:
  - Were involved with the incident (failed inspection)?
  - Missed the defect?
  - Observed the inspection?
  - Identified/detected the defect?
  - Reported the defect?
- What were:
  - The qualifications of these personnel?
  - The experience levels of these personnel?
  - The work groups of these personnel?
  - The attitudes of these personnel?
- Did the personnel involved:
  - Have adequate instruction?
  - Have adequate supervision?
  - Have adequate training?
  - Have adequate knowledge?
  - Communicate effectively?
  - Perform correct actions?
  - Worsen the condition?
  - Mitigate the condition?

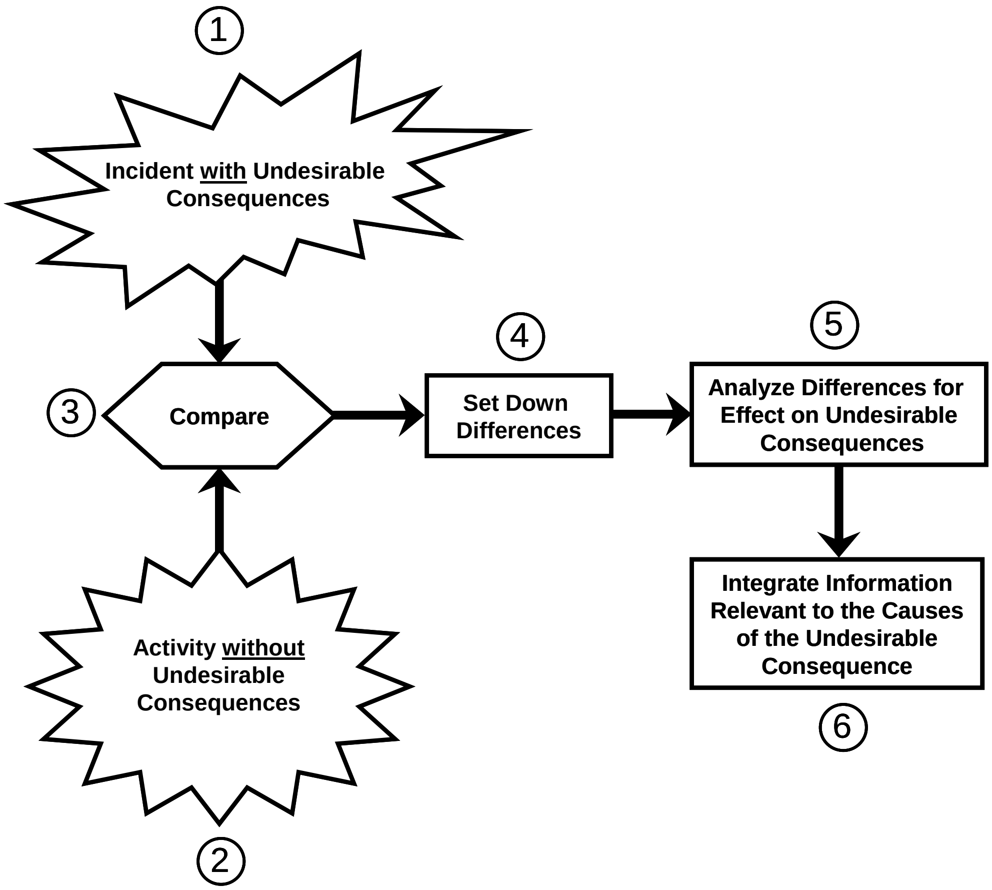



***Figure C1. Six Steps Involved in Change Analysis***

| Change Factor | Difference/Change | Effect | Question to Answer |
|---|---|---|---|
| **What?**<br>(Conditions, , activity, equipment) | | | |
| **When?**<br>(Occurred, identified, schedule) | | | |
| **How?**<br>(Work practice, omission, extraneous action, out of sequence procedure) | | | |
| **Who**<br>(Personnel involved, training, qualification, supervision | | | |

***Figure C-2. Change Analysis Worksheet***

# APPENDIX D

# HUMAN PERFORMANCE EVALUATION

Human performance evaluation is the assessment of the human interaction in the performance of specific tasks. Performance of human dependant tasks can be subdivided into four primary operations:

a. Input detection

b. Input understanding

c. Action selection

d. Action execution.

Facility and equipment operability, procedures and documentation, and management attitudes are all part of the work environment that needs to be evaluated for each of these steps. Common human factors problems to be considered are:

Inspector Factors:

- Cognitive overload
- Cognitive underload/boredom
- Habit intrusion
- Lapse of memory/recall
- Spatial misorientation
- Mindset/preconceived idea
- Tunnel vision or lack of big picture
- Unawareness
- Wrong assumptions made
- Reflect/instinctive action
- Thinking and actions not coordinated
- Insufficient degree of attention applied
- Shortcuts evoked to complete job
- Complacency/lack of perceived need for concern
- Confusion
- Misdiagnosis
- Fear of failure/consequences
- Fear of false-calls
- Fear of consequences of an inspection find (affecting mission)
- Tired/fatigued

Management Factors:

- Poor task management/assignment
- Insufficient time allotted for task
- Negative reinforcement
- Negative personality
- Inability to prioritize

- Inability to delegate
- Inability to set goals
- Inability to act on information
- Unawareness of personnel capabilities/training
- Unawareness of responsibilities, objectives and organizational capabilities
- Production/time/mission pressure
- Poor communication with subordinate personnel
- Poor communication with superiors
- Unfamiliarity with task requirements

Where high risk is very sensitive to noncompliance with requirements, each of the human performance factors should be considered in order to achieve a high degree of reliability. These factors also should be considered in system design/control and operator training, as well as causal factor determination and corrective action decisions.

# APPENDIX E

# CAUSE CODES

Note: Cause Codes can be tailored to a specific incident being investigated. The following Cause Codes have been developed for the investigation of the failure of a non-destructive inspection technique to detect an otherwise detectable defect or flaw in an aircraft structure.

**1. Equipment/Material Deficiency**

| | | |
|---|---|---|
| 1A | = | Defective probe, sensor, cable or connector |
| 1B | = | Defective instrumentation |
| 1C | = | Damaged equipment |
| 1D | = | Damage during shipping or error in marking |
| 1E | = | Equipment out of calibration |
| 1F | = | Electrical or instrument noise |
| 1G | = | Inadequate surface condition or surface contamination |
| 1H | = | Other equipment or material deficiency |

**2. Procedure Problem**

| | | |
|---|---|---|
| 2A | = | Defective or inadequate procedure |
| 2B | = | Lack of clarity in procedure |
| 2C | = | Lack of procedures (no procedures provided) |
| 2D | = | Lack of currency in procedure (i.e. current T.O. not available) |
| 2E | = | Procedure not properly validated or capability not verified |
| 2F | = | Other procedure problems |

**3. Personnel Error**

| | | |
|---|---|---|
| 3A | = | Inattention to detail |
| 3B | = | Violation of requirement or procedure (i.e., did not follow T.O.) |
| 3C | = | Verbal communication problem |
| 3D | = | Did not perform required inspection |
| 3E | = | Other human error |

**4. Design Problem**

| | | |
|---|---|---|
| 4A | = | Inadequate man-machine interface |
| 4B | = | Inadequate or defective NDI equipment design |
| 4C | = | Error in equipment or reference standard |
| 4D | = | Error in detection capability assumption |
| 4E | = | Error in inspection interval/damage propagation rate assumptions |
| 4F | = | Design crack scenario not representative of field observation |
| 4G | = | Drawing, specification, or data errors |
| 4H | = | Other design problem |

**5. Training Deficiency**

| | | |
|---|---|---|
| 5A | = | No training provided |
| 5B | = | Insufficient practice or hands-on experience |
| 5C | = | Inadequate training content |
| 5D | = | Insufficient refresher training |
| 5E | = | Inadequate presentation or materials |

| | | |
|---|---|---|
| 5F | = | Improper technician qualification level used for inspection |
| 5G | = | Other training deficiency |

**6. Management Problem**

| | | |
|---|---|---|
| 6A | = | Inadequate administrative control |
| 6B | = | Work organization/planning deficiency |
| 6C | = | Inadequate supervision |
| 6D | = | Improper resource allocation |
| 6E | = | Incorrect priority placed on inspection tasks |
| 6F | = | Insufficient time allotted for inspection tasks |
| 6G | = | Policy not adequately defined, disseminated, or enforced |
| 6H | = | Other management problem |

**7. External Phenomenon**

| | | |
|---|---|---|
| 7A | = | Poor weather |
| 7B | = | Poor ambient inspection conditions (e.g. too hot or cold, insufficient or excessive lighting) |
| 7C | = | Power failure or transient |
| 7D | = | External fire or explosion |
| 7E | = | Theft, tampering, sabotage, or vandalism |
| 7F | = | Location and accessibility of part being inspected |
| 7G | = | Physical position of inspector (ergonomics) |
| 7H | = | Amount of disassembly required |
| 7I | = | Other external phenomenon |

# APPENDIX F

# CAUSAL FACTOR WORKSHEETS

After the appropriate root cause methods have been used to identify the direct cause(s), the root cause, and any applicable contributing cause(s), these various causes can be categorized by using one or more of the worksheets in this appendix. Each of the seven major cause worksheets has a matrix to list the applicable subcategory cause for each finding. The same subcategory cause may be listed for up to four similar causes under columns I through IV. For similar causes, fill out Columns I through IV in order of impact or importance. .

Worksheet Instructions:

1. Check each worksheet as applicable or not applicable.

2. List subcategory cause information on each applicable worksheet.

    a. List the applicable subcategory cause for the root cause, the contributing causes, and the direct cause by placing an R, C, or D in the appropriate box. (The same cause may be listed for up to four similar findings; for example, four different missed cracks).

    b. Under cause description, reference each cause with the code and Roman numeral from the matrix and describe each cause (explain how it was related to the incident).

    c. Select the most direct causes and the root causes (the ones for which corrective action will prevent recurrence and have the greatest, most widespread effect). In cause selection, focus on programmatic and system deficiencies and **avoid simple excuses such as blaming the inspector**. Note that the root cause or causes must be an explanation (the why) of the direct causes, not a repeat of the direct cause. In addition, a cause description is not just a repeat of the category code description; it is a description specific to the incident (failed inspection).

    d. Under recommended corrective actions, list the action intended to correct each cause to prevent recurrence. Describe the corrective actions selected to prevent recurrence, including the reason why they were selected, and how they will prevent recurrence.

3. Transfer the direct, the root, and contributing causes and the corrective actions to the Worksheet Summary. When there are more than three contributing causes, select those that result in the greatest and most widespread improvement when corrected. Rank order the causes in order of significance in columns I through IV.

(Note that even though only three contributing causes may be reported, corrective actions should be made for all identified causes).

## 1. Equipment/Material Worksheet

☐ **Applicable** ☐ **Not Applicable**

### Why was "Equipment/Material" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **Equipment/Material Problem Cause Codes** | **I** | **II** | **III** | **IV** |
| 1A = Defective probe, sensor, cable or connector | | | | |
| 1B = Defective instrumentation | | | | |
| 1C = Damaged Equipment | | | | |
| 1D = Damaged equipment during shipping or error in marking | | | | |
| 1E = Equipment out of calibration | | | | |
| 1F = Electrical or instrument noise | | | | |
| 1G = Inadequate surface condition or surface contamination | | | | |
| 1H = Other Equipment/Material Problem | | | | |

Cause Description:

Recommended Corrective Actions:

## 2. Procedure Problem

☐ **Applicable** ☐ **Not Applicable**

### Why was a "Procedure Problem" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

| **Procedure Problem Cause Codes** | **Causes** I | II | III | IV |
|---|---|---|---|---|
| 2A = Defective or inadequate procedures | | | | |
| 2B = Lack of clarity in procedure | | | | |
| 2C = Lack of procedures (no procedures provided) | | | | |
| 2D = Lack of currency in procedure (T.O. not updated) | | | | |
| 2E = Procedures not properly validated or capability not verified | | | | |
| 2F = Other procedure problem | | | | |

D = Direct Cause
C = Contributing Cause
R = Root Cause

Cause Description:

Recommended Corrective Actions:

## 3. Personnel Error

☐ **Applicable** ☐ **Not Applicable**

### Why was "Personnel Error" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **Personnel Error Cause Codes** | **I** | **II** | **III** | **IV** |
| 3A = Inattention to detail | | | | |
| 3B = Violation of requirement or procedure (i.e., id not follow T.O.) | | | | |
| 3C = Verbal communication problem | | | | |
| 3D = Did not perform required inspection | | | | |
| 3E = Other human error | | | | |

Cause Description:

Recommended Corrective Actions:

## 4. Design Problem

☐ **Applicable** ☐ **Not Applicable**

### Why was the "Design" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **Design Problem Cause Codes** | **I** | **II** | **III** | **IV** |
| 4A = Inadequate man-machine interface | | | | |
| 4B = Inadequate or defective NDI equipment design | | | | |
| 4C = Error in equipment or reference standard | | | | |
| 4D = Error in detection capability assumption | | | | |
| 4E = Error in inspection interval/damage propagation rate assumption | | | | |
| 4F = Design crack scenario not representative of field observation | | | | |
| 4G = Drawing, specification or data errors | | | | |
| 4H = Other Design Problem | | | | |

Cause Description:

Recommended Corrective Actions:

## 5. Training Deficiency

☐ **Applicable** ☐ **Not Applicable**

### Why was a "Training Deficiency" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **Training Deficiency Cause Codes** | **I** | **II** | **III** | **IV** |
| 5A = No Training provided | | | | |
| 5B = Insufficient practice or hands-on experience | | | | |
| 5C = Inadequate training content | | | | |
| 5D = Insufficient refresher training | | | | |
| 5E = Inadequate presentation materials | | | | |
| 5F = Inadequate technical qualification level used for inspection | | | | |
| 5G = Other training deficiency | | | | |

Cause Description:

Recommended Corrective Actions:

## 6. Management Deficiency

☐ **Applicable** ☐ **Not Applicable**

### Why was a "Training Deficiency" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **Management Deficiency Cause Codes** | **I** | **II** | **III** | **IV** |
| 6A = Inadequate administrative control | | | | |
| 6B = Work organization/planning deficiency | | | | |
| 6C = Inadequate supervision | | | | |
| 6D = Improper resource allocation | | | | |
| 6E = Incorrect priority placed on inspection tasks | | | | |
| 6F = Insufficient time allotted for inspection tasks | | | | |
| 6G = Policy Not Adequately Defined, Disseminated or Enforced | | | | |
| 6H = Other management problem | | | | |

Cause Description:

Recommended Corrective Actions:

## 7. External Phenomenon

☐ **Applicable** ☐ **Not Applicable**

### Why was an "External Phenomenon" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **External Phenomenon Problem Cause Codes** | **I** | **II** | **III** | **IV** |
| 7A = Poor weather | | | | |
| 7B = Poor ambient conditions (e.g. too hot, too cold, poor lighting) | | | | |
| 7C = Power failure or transient | | | | |
| 7D = External fire, explosion or emergency | | | | |
| 7E = Theft, tampering, sabotage or vandalism | | | | |
| 7F = Location and accessibility of part being inspected | | | | |
| 7G = Physical position of inspector (ergonomics) | | | | |
| 7H = Amount of disassembly required | | | | |
| 7I = Other external phenomenon | | | | |

Cause Description:

Recommended Corrective Actions:

# Worksheet Summary

| Problem/Deficiency Category | | Direct Cause | Root Cause | Contributing Cause |
|---|---|---|---|---|
| Operational Readiness Problem | Equipment/ Material Problem | | | |
| | Procedure Problem | | | |
| | Personnel Error | | | |
| Management/Field Bridge Problem | Design Problem | | | |
| | Training Deficiency | | | |
| Management Problem | | | | |
| External Phenomenon | | | | |

Cause Description:

Corrective Actions:

# APPENDIX G

# EXAMPLE INCIDENT ANALYSIS

Incident Description

A 30 day time compliance technical order (TCTO) was released requiring the eddy current inspection of the wing flap track on a dual engine US Air Force aircraft. The TCTO tech data was successfully validated by depot NDI and structural engineering prior to TCTO release. The TCTO was scheduled to be accomplished on 21 December 2004, on A/C 90-678 prior to a scheduled 7:00 AM training mission. The aircraft was grounded pending successful performance of the TCTO. The inspector assigned to the inspection task was late arriving to work. No other inspection personnel were available at the time due to holiday vacations. To expedite flight preparations, the crew chief rolled the aircraft out of the hangar at 8:00 AM to perform an engine check. At 9:35 AM the inspector arrives at work and is assigned the task by his supervisor. At 10:00 AM the inspector arrives at the aircraft and performs the inspection. The outdoor ambient temperature was 25ºF with light winds at the time of the inspection. The indoor ambient condition where the inspection equipment was stored was 65ºF. On 27 February 2005, A/C 90-678, experienced an in-flight failure of the left engine, declared an in-flight emergency and landed safely at a local municipal airport. The incident was classified in a Class A mishap as it resulted in greater than $500K of damage the aircraft.

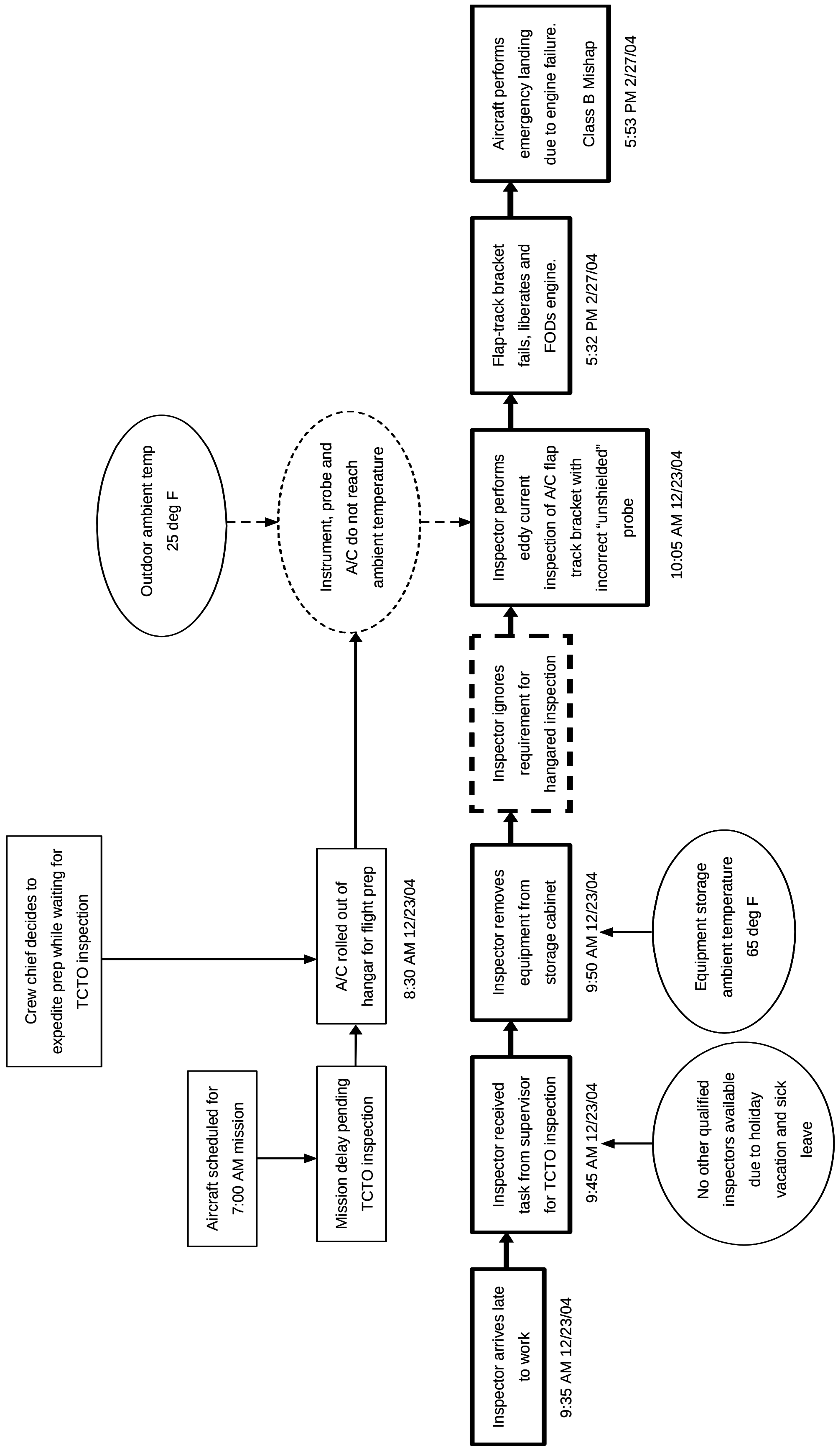
A subsequent failure analysis revealed that the left-wing flap-track failed, resulting in the in-flight liberation of a mounting bracket. The bracket was ingested by the engine, resulting in FOD damage and engine failure. Laboratory analysis indicted the flap track failed due to fatigue. Analysis also indicates that the crack was between $a_{NDI}$ and < $a_{critical}$ ($a_{NDI}$ but < $a_{critical}$) was present during the previous inspection.

Findings:

The resulting investigation revealed that the inspector violated procedural requirements and elected to ignore TCTO requirements for aircraft hangaring during inspection. Furthermore the inspector did not allow inspection equipment, probes and reference standard to reach ambient conditions prior to beginning the inspection. Interviews with the inspector also revealed the inspector used the incorrect "unshielded" probe. A shielded probe was required by the part specific procedure to inspect around a ferromagnetic fastener. The inspector inadvertently selected the incorrect probe and only realized the mistake during the inspection. Due to schedule and pervasive command pressures the inspector elected to complete the inspection with the "unshielded" probe. Failure to use the correct probe combined with the failure to perform the inspection in a temperature controlled environment (hanger) resulted in inspection noise, excessive instrument drift and misinterpretation of inspection results, ultimately leading to the failure to detect an otherwise detectable fatigue crack.

- **Direct Cause**: Failure of the inspector to use the correct probe during the inspection.
- **Contributing Causes**
    - Failure of the inspector to perform the inspection in a temperature controlled environment.
    - Pressure to complete the inspection when unprepared.
- **Root Causes**:
    - Failure of management to ensure sufficient personnel resources to address mission needs.

- Failure of the organization to enforce a culture of professionalism and safety-consciousness in the workplace.



Aircraft scheduled for 7:00 AM mission
Mission delay pending TCTO inspection
Crew chief decides to expedite prep while waiting for TCTO inspection
A/C rolled out of hangar for flight prep
8:30 AM 12/23/04
Outdoor ambient temp 25 deg F
Instrument, probe and A/C do not reach ambient temperature
Inspector arrives late to work
9:35 AM 12/23/04
Inspector received task from supervisor for TCTO inspection
9:45 AM 12/23/04
No other qualified inspectors available due to holiday vacation and sick leave
Inspector removes equipment from storage cabinet
9:50 AM 12/23/04
Equipment storage ambient temperature 65 deg F
Inspector ignores requirement for hangared inspection
Inspector performs eddy current inspection of A/C flap track bracket with incorrect "unshielded" probe
10:05 AM 12/23/04
Flap-track bracket fails, liberates and FODs engine.
5:32 PM 2/27/04
Aircraft performs emergency landing due to engine failure.
Class B Mishap
5:53 PM 2/27/04

## 1. Equipment/Material Worksheet

[ ] **Applicable** [XX] **Not Applicable**

### Why was "Equipment/Material" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **Equipment/Material Problem Cause Codes** | **I** | **II** | **III** | **IV** |
| 1A = Defective probe, sensor, cable or connector | | | | |
| 1B = Defective instrumentation | | | | |
| 1C = Damaged Equipment | | | | |
| 1D = Damaged equipment during shipping or error in marking | | | | |
| 1E = Equipment out of calibration | | | | |
| 1F = Electrical or instrument noise | | | | |
| 1G = Inadequate surface condition or surface contamination | | | | |
| 1H = Other Equipment/Material Problem | | | | |

## 2. Procedure Problem

[ ] **Applicable** [XX] **Not Applicable**

### Why was a "Procedure Problem" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **Procedure Problem Cause Codes** | **I** | **II** | **III** | **IV** |
| 2A = Defective or inadequate procedures | | | | |
| 2B = Lack of clarity in procedure | | | | |
| 2C = Lack of currency in procedure (T.O. not updated) | | | | |
| 2D = Lack of currency in procedure (T.O. not updated) | | | | |
| 2E = Other procedure problem | | | | |

## 3. Personnel Error

| XX | Applicable | | Not Applicable |
|---|---|---|---|

### Why was "Personnel Error" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| **Personnel Error Cause Codes** | **Causes I** | **II** | **III** | **IV** |
|---|---|---|---|---|
| 3A = Inattention to detail | | | | |
| 3B = Violation of requirement or procedure (i.e., id not follow T.O.) | D | C | | |
| 3C = Verbal communication problem | | | | |
| 3D = Did not perform required inspection | | | | |
| 3E = Other human error | | | | |

Cause Description:

**3A-I Violation of Requirement or Procedure**. Direct Cause: The inspector elected to violate procedure and use incorrect "unshielded" probe.

**3A-II Violation of Requirement or Procedure.** Contributing Cause: The inspector elected to ignore procedure requirements to perform inspection in a temperature stable environment i.e. hangar.

Recommended Corrective Actions:

1. Train personnel on the role of inspections to maintain flight safety and the critical nature of the task
2. Emphasize a Safety-First culture

## 4. Design Problem

| | Applicable | XX | Not Applicable |
|---|---|---|---|

### Why was the "Design" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| **Design Problem Cause Codes** | **Causes I** | **II** | **III** | **IV** |
|---|---|---|---|---|
| 4A = Inadequate man-machine interface | | | | |
| 4B = Inadequate or defective NDI equipment design | | | | |
| 4C = Error in equipment or reference standard | | | | |
| 4D = Error in detection capability assumption | | | | |
| 4E = Error in inspection interval/damage propagation rate assumption | | | | |
| 4F = Design crack scenario not representative of field observation | | | | |
| 4G = Drawing, specification or data errors | | | | |
| 4H = Other Design Problem | | | | |

## 5. Training Deficiency

[ ] Applicable  [XX] Not Applicable

### Why was a "Training Deficiency" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **Training Deficiency Cause Codes** | **I** | **II** | **III** | **IV** |
| 5A = No Training provided | | | | |
| 5B = Insufficient practice or hands-on experience | | | | |
| 5C = Inadequate training content | | | | |
| 5D = Insufficient refresher training | | | | |
| 5E = Inadequate presentation materials | | | | |
| 5F = Inadequate technical qualification level used for inspection | | | | |
| 5G = Other training deficiency | | | | |

## 6. Management Deficiency

[XX] Applicable  [ ] Not Applicable

### Why was a "Training Deficiency" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **Management Deficiency Cause Codes** | **I** | **II** | **III** | **IV** |
| 6A = Inadequate administrative control | | | | |
| 6B = Work organization/planning deficiency | | | | |
| 6C = Inadequate supervision | | | | |
| 6D = Improper resource allocation | R | | | |
| 6E = Incorrect priority placed on inspection tasks | R | | | |
| 6F = Insufficient time allotted for inspection tasks | C | | | |
| 6G = Policy Not Adequately Defined, Disseminated or Enforced | | | | |
| 6H = Other management problem | | | | |

Cause Description:

**6D-I Improper Resource Allocation**. Root Cause. Supervision failed to ensure sufficient qualified personnel were scheduled to work to meet mission needs

**6E-I Incorrect Priority Placed on Inspection Tasks.** Organization and management culture emphasizes schedule over safety.

**6F-I Insufficient Time Alotted for Inspection Task.** Undue pressure was placed on the inspector to rapidly complete the safety-critical inspection. This pressure indirectly influenced inspector to ignore specific procedural guidance in order to rapidly clear the aircraft for flight.

Recommended Corrective Actions:

1. Seek efficiencies in other operations to free up additional time for inspection
2. Conduct manpower review to assess availability of qualified personnel to meet mission needs including primary and backup personnel
3. Establish and enforce policies to establish inspection as a Safety-Critical event that will drive schedule
4. Hold management accountable for manpower availability

## 7. External Phenomenon

| XX | **Applicable** | | **Not Applicable** |
|---|---|---|---|

### Why was an "External Phenomenon" a Cause?

**Rate each cause as D,C or R for each of the applicable cause codes:**

D = Direct Cause
C = Contributing Cause
R = Root Cause

| | Causes | | | |
|---|---|---|---|---|
| **External Phenomenon Problem Cause Codes** | **I** | **II** | **III** | **IV** |
| 7A = Poor weather | | | | |
| 7B = Poor ambient conditions (e.g. too hot, too cold, poor lighting) | C | | | |
| 7C = Power failure or transient | | | | |
| 7D = External fire, explosion or emergency | | | | |
| 7E = Theft, tampering, sabotage or vandalism | | | | |
| 7F = Location and accessibility of part being inspected | | | | |
| 7G = Physical position of inspector (ergonomics) | | | | |
| 7H = Amount of disassembly required | | | | |
| 7I = Other external phenomenon | | | | |

Cause Description:

**7B-I Poor Ambient Conditions.** Contributing Cause - Low outdoor ambient temperature resulted in excessive instrument drift.

Recommended Corrective Actions:

1. Retrain inspectors on effects of unstable ambient conditions on inspection stability and the criticality of following procedural guidance with an emphasis on requirements for hangared inspections.

# Worksheet Summary

| Problem/Deficiency Category | | Direct Cause | Root Cause | Contributing Cause |
|---|---|---|---|---|
| Operational Readiness Problem | Equipment/ Material Problem | | | |
| | Procedure Problem | | | |
| | Personnel Error | 3B-I | | 3B-II |
| Management/Field Bridge Problem | Design Problem | | | |
| | Training Deficiency | | | |
| Management Problem | | | 6D, 6E | 6F |
| External Phenomenon | | | | 7B |

**Cause Description:**

The direct cause if the incident was the inspector violated procures and used an incorrect "unshielded" probe during the inspection. Contributing causes were a) the inspector was pressured to rush the inspection b) the inspector elected to violate procedures and perform an unhangared inspection and c) the cold ambient outdoor conditions resulted in excessive instrument drift. Root causes were the supervisor did not ensure sufficient manpower to meet mission needs and the overarching organizational structure emphasizing schedule over safety concerns.

**Corrective Actions:**

1. Seek efficiencies in other operations to free up additional time for inspection.
2. Conduct manpower review to assess availability of qualified personnel to meet mission needs including primary.
3. Establish and enforce policies to establish inspection as a Safety-Critical event that will drive schedule.
4. Hold management accountable for manpower availability.
5. Train personnel on the role of inspections to maintain flight safety and the critical nature of the task.
6. Emphasize a Safety-First culture.
7. Hold inspection personnel accountable to completely follow inspection tech data requirements.