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## **Failure Appraisalment**

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# Failure Appraisalment

## **Preface**

Failure! Why did it happen? Good question! It may have happened to a technical product, an economic investment, a biological condition, or in many other circumstances. Chances are, someone will want to know why such a failure occurred.

Engineers are frequently called upon to find, or are faced with the need to know, the reason for a failure. In the course of your engineering career, you may have on occasion been faced with the task of determining why, or how, a failure has occurred. Besides the economic issues associated with such a failure, there may be safety or other important consequences. Determination of the characteristics of and the reason for failure may be vital. In order to properly, and successfully, assess failures it is necessary to follow a suitable procedure.

This course describes principles and techniques that are helpful in guiding a successful failure appraisal.

Loering M. Johnson, P.E.(ret.)

## **Introduction:**

This course is called "Failure Appraisalment" because it deals with general principles and methods in investigating failures. More detailed, rigorous, and mathematically-based evaluation of failures is usually called "failure analysis". The approach presented in this course could be sufficient for the evaluation of a simple failure or it could be a good starting point for the more detailed investigation of extensive and complicated failures and may afford a saving of analysis time and effort.

The student is reminded that the generalized principles and approaches presented in this course may have to be modified in a particular failure investigation. The circumstances and effects of different failures vary widely and the selected approach needs to be adapted to the characteristics of the failure being considered.

In this course, the following definitions apply:

1. Failure - a loss of function resulting in the inability to perform a duty or expected action; a state of instability resulting in loss of capacity to perform a normal function.
2. Appraisalment - an evaluation of the worth, significance, or status of; an expert judgment of the significance or reason for.

3. Root Cause – the basic or fundamental cause of the failure being investigated; the cause which, if changed or corrected, can prevent recurrence of the problem.

4. Limit – a confining or restricting object, agent, or influence.

### **Appraisal Bases:**

In approaching the appraisal of a failure, a first step is to identify the bases for action. These bases should include a characterization of the value and importance (the significance) of the failure. For instance, the bases of a failure investigation might be:

- Safety - loss of life or injury to persons; possible danger to persons or property; disaster or catastrophe avoidance.
- Economic - property damage, loss of product, increased costs, loss of needed service, basis for design change, or similar requirements.
- Necessity , the subject service or operation is needed, replacement(s) is/are not available; it is essential to find out what needs to be repaired.
- Knowledge - why did this item fail?; personal education for future guidance.

Identification of the bases for investigating a failure is important in;

- establishing how the investigation is to proceed; for instance, determining the course(s) of action, the care and protection that is to be provided for the items involved, the timing that is to be observed, and the records that are to be kept.
- determining what resources are to be assigned to the investigation; this may include the access of special equipment or personnel that must be arranged for, obtaining necessary funds and authorization, and checking for regulations or constraints that apply.
- specifying what is to be done with the findings; the extent of the records and reports that are to be prepared, their format, and the recipient(s) of them.

Following the characterization of the bases for failure investigation, an important next step is to determine (and document if appropriate) the available information. One needs to consider:

- (1) what is known - all the facts that are pertinent to this situation should be recognized; especially important in the case where investigation or other activity may disturb the item and any important surroundings. If the first choices of action do not lead to the location of the underlying cause and

alternative routes must be investigated, information that initially seemed trivial may become important. All available information should be noted.

- (2) what is noted or observed about the failure - care must be taken to assure that as much pertinent data as possible is collected; this includes data that, at the time may seem to be irrelevant, but may later be found to be important. This is especially important in the case of accidents or other situations where the conditions or circumstances may be eliminated or contaminated after initial inspection.
- (3) what is not known, but which may be related or important. Here the items, conditions, or influences that are missing or are expected, but absent, are important. Also, the condition of items related to or associated with missing or absent items may be important in helping to explain the absence.

In this information collection, it is also important to list assumptions that are used as guides in the investigation. In listing these assumptions, it may be desirable to indicate the degree of certainty that each one has. And during the investigation these assumptions should be confirmed or modified as the findings direct. If the findings in the investigation do not produce satisfactory results, it may be that the assumptions made are not correct or suitable. Here the indicated degree of certainty may be helpful in modifying the assumption or in selecting a new direction for the investigation. Investigators must be willing to change direction or approach to ascertain the basic cause or reason that the failure in question has occurred.

**Failure causes are frequently not what seems to be most obvious or what is first suspected. And failures seldom have a single cause. Usually failures occur because of a combination of two or more degrading factors.**

### **The appraisal process:**

Generally the objective of failure appraisal is the determination of a basic reason that the failure occurred. This basic or fundamental reason is also known as the Root Cause of failure. (See Introduction – Definitions.)

Failure, in the context considered here, may be as trivial and simple as one's pen being unable to write or as important and complicated as the Columbia tragedy or the NYC twin towers collapse. Appraisal of the fundamental reason for these failures is based on a common process; but the degree of detail, effort, and cost is different.

In expanding the process to enable the inclusion and evaluation of greater detail, much care should be used. In some cases, such as the Columbia loss, it may be possible to recover most, or many, of the pieces or parts. These may then be grouped in positions that afford a visible clue as to what articles or components were affected most. Special attention should be given to missing items. What cannot be found may be very important.

On the other hand, the primary evidence may not be available. A ship or airplane may have sunk and cannot be retrieved. Pieces and parts of items involved may have been destroyed by fire, carried away by a flood or tornado, or have been destroyed or dissipated and are not available. In these cases, secondary evidence such as transmitted data, design or fabrication records, pictures, historical descriptions, and information supplied by witnesses or observers may be important.

### **Appraisement Procedure:**

A suggested procedure is first to enumerate;

1. The bases for the particular investigation.
2. Constraints that exist or may be encountered; e.g. access, regulations, hazards.
3. The requirements to be met; e.g. time schedule, findings recipient, results format.
4. Aids, facilities, and services needed. These may include personnel, structures, money, tools, equipment, and information.

Then to;

5. Describe the failure as well as possible. Describe the item, the situation, the existing conditions, anticipated failure modes, etc.
6. List pertinent known data. This includes relevant information and evidence on components and observations such as items available/found – yes or no --, where found, what condition/damage, and estimates of how this condition might have occurred.
7. List what is not known that would be of assistance.
8. Describe the assumptions. The assumptions may be crucial to the success of the investigation. There are cases where an action seemed to be possible, but a review of the assumptions on which the action was based showed that some of the assumptions were incorrect and the predicted action was therefore impossible.

This writer was once involved in the resolution of a problem in which an electro-mechanical system that used balanced electronic networks in its operation was operating erratically. One of the assumptions was that the individual components were proper and suitable. A detailed examination of the circuits showed that some of the components, while meeting the procurement specifications, had slightly different performance characteristics over their range of operation. When these components were replaced with matched

sets, the erratic operation of the system was eliminated.

9. Select an approach to find causes. Here it is important to watch out for false trails; to carefully review assumptions, unknowns, and evidence to most effectively use resources and time. It may be that repeatedly asking “why” (did this occur) and finding an answer will lead to the discovery of the Root Cause. Or, alternatively, doing the same with “Because” would be more suitable.

It may be helpful to employ diagrams in structuring the investigation. Such diagrams are especially useful in cases where there are many pieces to the puzzle and no clear direction for investigation. Diagrams are also very useful when the investigation is being conducted by a team (or teams) as they enable all involved to understand, evaluate, and direct action more easily.

Visual aids such as Fishbone or Ishikawa diagrams or Tree diagrams are useful candidates for this activity. Fishbone diagrams offer a simple way to categorize and list problem areas for the simpler investigations. Tree diagrams can offer more detail if such is necessary; showing primary, secondary, tertiary, etc., relationships and problem areas.

Or, in a case where many items must be considered, tracked, and/or related, it may be preferable to employ a spreadsheet technique in which it is possible to list many items, note their associated availability, condition, importance, function, limitations, and other data and to use mathematical relationships to assist with the evaluation.

Use of a spreadsheet (e.g. Microsoft’s Excel or Corel’s Quattro Pro) would enable a much more detailed approach in which formula and calculations could be used for failure analyses. The spreadsheet might include;

- categories, subcategories, etc. that are logical and appropriate.
- designation of the importance or relation of items in the system
- estimation of likelihood, or calculation of probability, of failure
- availability of items (present, missing, expended, etc.) and condition
- known reasons for the condition or absence of items
- changes or interactions that occurred during the failure
- directions and priorities for the investigation
- schedule of tests and analyses and their reports
- preparation and delivery of conclusions

10. Pursue the investigation. At various steps, associate evidence and observations with expected behavior or performance. Perform experiments or analyses if necessary to confirm relationships. Analyses may include examinations (e.g. metallurgical, microscopic, medical, etc.) and computations utilizing probabilities and graphs. Use the results of these analyses to guide and substantiate conclusions.

**At some point in the questioning or investigation, a limit will be encountered. This limit may be a natural law, a regulation, an**

**established rule of practice, or a physical limitation of materials involved. At this point, select the preceding step and establish that occurrence as the Root Cause of the failure.**

11. Evaluate results to confirm that the cause identified is the Root Cause. If possible develop evidence to show that the selected cause is the Root Cause. If, however, there is insufficient evidence because of missing items or available information, it may be necessary to conclude that the suspected cause found is the "Most Probable" Root Cause.

And finally:

12. Document the appraisal process and conclusions as appropriate. In the case of safety or economic bases, there may be established formats or requirements to be followed (as noted in the constraints).

Even in the case of the investigation of a simple failure for personal knowledge, it may be desirable to document the process and findings so that at a future date the details are not forgotten and recovery from future similar failures can be more rapid and less costly.

Preparing this documentation is also valuable in personal training to learn to evaluate failures. Such training may be a key step in successful innovation and entrepreneurial endeavors.

### **Example:**

As an example of the implementation of the Appraisal Procedure, consider the failure of a lawn mower to operate properly. In this case, the motor after running well was shut off for a few minutes while other work was performed, but would not restart. However, after sitting for about two hours the motor restarted easily and ran correctly. This process was repeated several times to demonstrate that the failure characteristics were repeatable.

### **Equipment Description**

- mower
  - push type
  - 21-inch blade
  - directly-driven blade
  
- engine
  - Briggs & Stratton, four-cycle
  - two horsepower, vertical shaft
  - suction-feed carburetor
  - rope starter

- recent maintenance
  - new spark plug installed
  - breaker points cleaned and the gap set
  - blade sharpened and balanced

### Applying the suggested procedure steps in this Example

1. Bases for the investigation
  - restore mower to normal operation to enable lawn to be cut
  - satisfy personal curiosity
  - assist future mower maintenance
  
2. Constraints
  - working time is limited
  - financial expenditure is limited
  - available information is limited
  
3. Requirements to be met
  - restore the motor to normal operation as soon as possible
  - prepare understandable documentation of the findings and corrective action
  - put documentation in mower file for future reference
  
4. Aids, facilities, and services needed
  - a work area
  - wrenches, a volt-ohmmeter, a flywheel puller, other tools
  - maintenance manual for the engine
  
5. Describe the failure
  - the motor started initially on the first pull of the rope starter
  - the mower operated satisfactorily
  - the motor was shut off briefly while other tasks were performed
  - on attempt to restart, the motor would not start even after numerous pulls of the rope starter
    - one or more “pop” sound heard with each rope pull
    - lack of gasoline suspected; gas tank checked -- found half full
    - spark plug fouling suspected; plug removed/inspected – not fouled
    - mower was left to sit for about two hours
  - another restart attempted; motor started on first pull of the rope starter
  - after running a few minutes, the motor was stopped and a restart attempted
    - motor would not start even after numerous pulls of the rope starter
    - “pop” sounds heard with each rope pull
  
6. List known data
  - no items are missing or unavailable
  - an easy restart after sitting for a time shows that the principal system components are operational

- a check of the gas supply and the spark plug condition eliminated these possibilities as the causes of failure
- the failure to immediately restart after running shows that there is a malfunction

7. What is not known that would be of assistance

- where does the “pop” sound come from?
- is there a short or open in the high-voltage coil or the wiring when they are hot?

8. Assumptions

- the main motor parts (crankshaft, piston, valves) are operational
- gasoline being used is of satisfactory quality
- the high tension lead is OK
- the magnet air gap is proper
- the high and low idle jets are set correctly

9. Select probable causes; establish the course of investigation

In this example, the simple approach of using “Why’s” or “Because’s” is not adequate, as the reason for some of the “Why’s” cannot be determined. An investigation is necessary; more detail is needed. Diagrams are of assistance here.

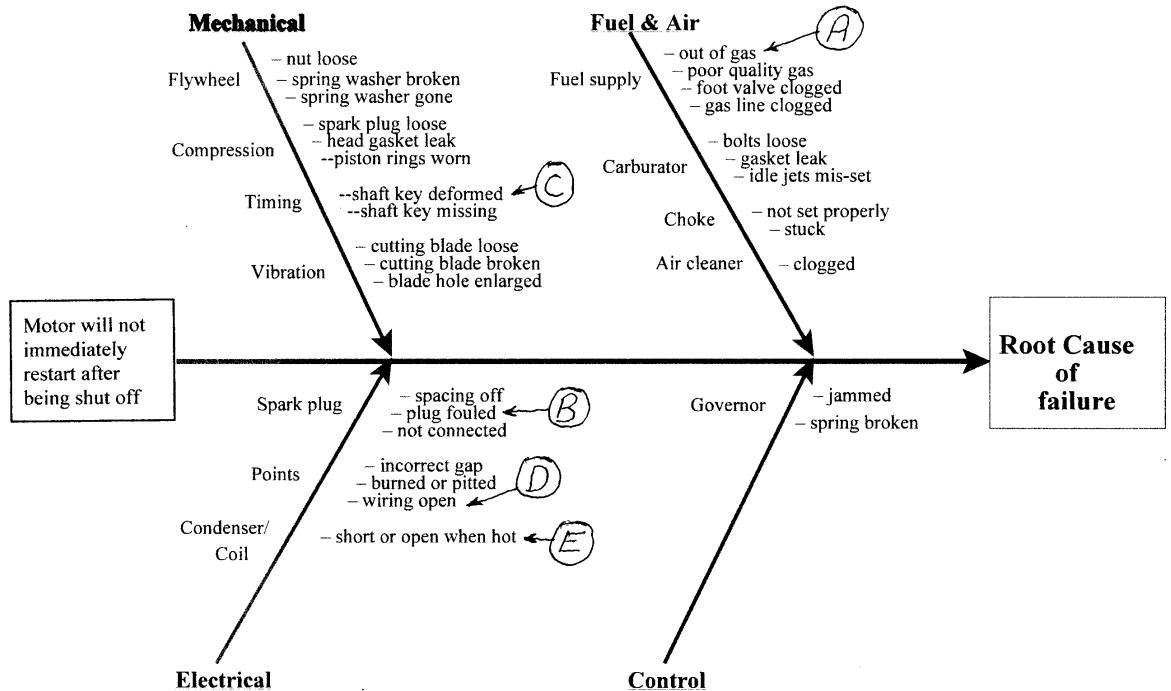


Figure 1

- Figure 1 shows an Ishikawa/Fishbone diagram with possible problems listed in Mechanical, Fuel & Air, Electrical, and Control categories. Most likely causes of failure have been marked A, B, C, D, and E in order of

their likelihood of occurrence.

- Figure 2 shows a Tree diagram with the same information presented. Note that the Tree diagram affords more levels of detail and perhaps more understandable categorization.

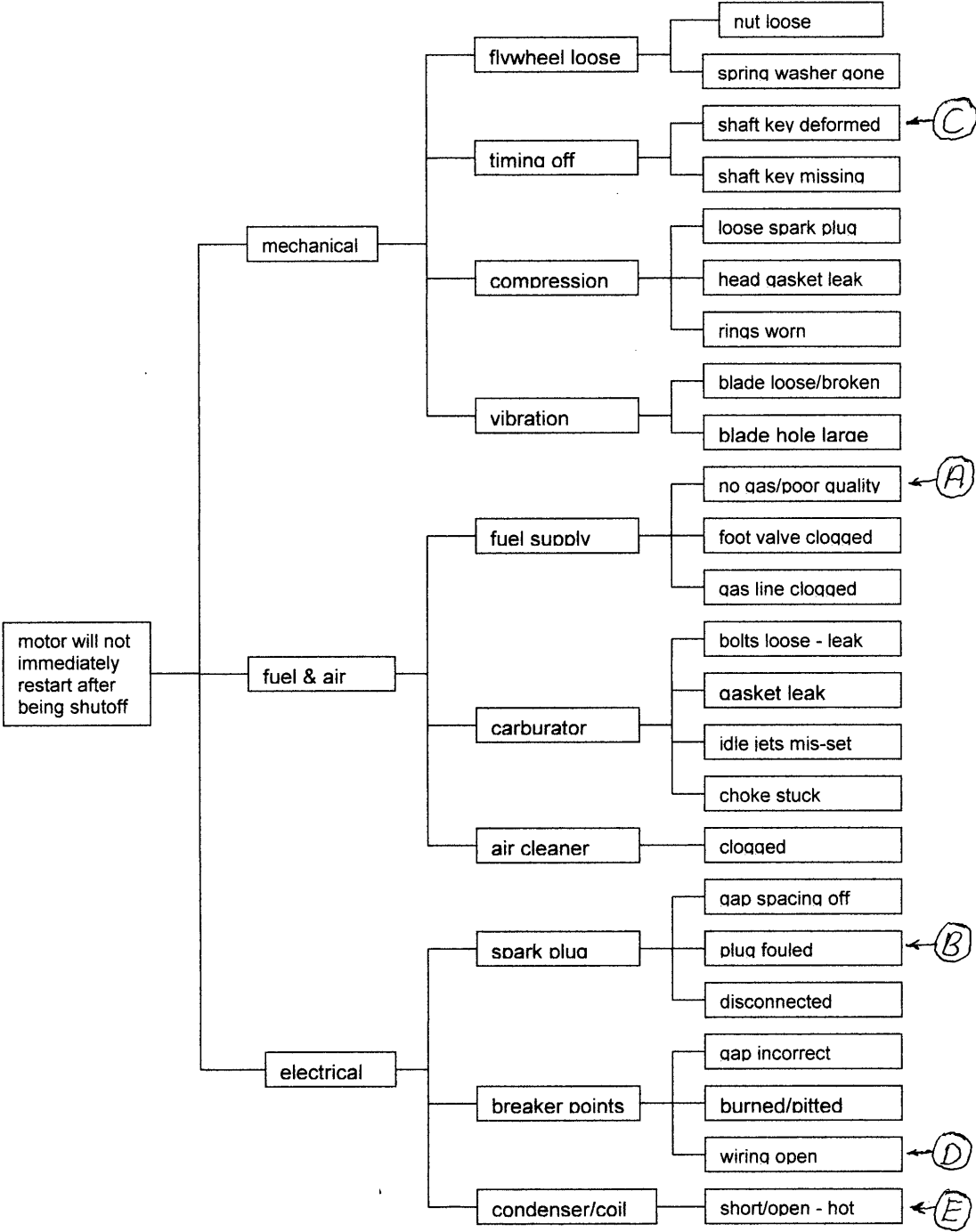


Figure 2

#### 10. Pursue the investigation

- The gas supply and spark plug fouling have already been eliminated as potential causes in this example. Next in order of priority (item C) is an investigation of the timing. Starter assembly and flywheel were removed. The shaft key is in place and is not deformed which indicates suitable timing. Next to be checked are the breaker points and ignition wiring. Upon removal of the metal cover, the ignition compartment (see Figure 3) is found to contain a significant portion of oil.



**Figure 3**

Now the reason for failure is exposed. The breaker points are in close proximity to the upper section of the crankshaft on which there is an oil seal. Wear of the seal (after several thousand hours of motor operation) has enabled oil to be pumped up the shaft and slung into the ignition compartment. As long as the motor is running, the rapid action of the breaker points shakes off the oil so that a spark can be generated. When the motor is shut off, the oil collects on the points and, when a restart is attempted, shorts the spark to ground. The “pop” sound that is heard is an exploding oil droplet as it shorted the spark.

**The natural law that is encountered here is that bearings and seals**

**wear. Backing up one step from this natural law leaves ‘a worn upper oil seal’ as the Root Cause of failure in this example.**

- To verify that this cause is the Root Cause, the upper oil seal was replaced and the ignition compartment and its contents were cleaned of oil. Flywheel and starter assembly were replaced. The motor was then started easily, stopped, and restarted. This process was repeated several times, confirming that the worn oil seal was the Root Cause of this failure.

This example demonstrates that the anticipated cause of failure is not always the one found to be the real cause. It also shows that there can be related causes or degrading factors. In this example, the upper crankshaft bearing is probably also worn and this led to increased wear on the upper oil seal.

12. The investigation procedure, the findings, and the conclusions were documented and placed in the mower maintenance file for future reference.

### **Conclusion:**

The process of Failure Appraisal is important in:

1. Enabling a structured approach to the determination of why a failure occurred.
2. Learning to adapt and modify the structure as appropriate for the particular failure being investigated in order to save time and make most effective use of resources.
3. Helping individual(s) involved develop the thoughts and procedures appropriate for failure investigation. This is especially important if one is involved (or planning to be involved) in forensic activities concerning failures.