Chapter 5 – FAILURE INVESTIGATIONS: A POSSIBLE WORK PROCEDURE

Maj. L. Aiello
USA

5.1 INTRODUCTION

Any failure occurring on structural materials applied on air platforms needs to be studied, in order to avoid other accidents which are going to happen on aircraft of same fleet. Though, economic and safety issues are the driving forces to develop more efficient failure analysis and investigations.

Due to the need to set up the capability to share information on failed parts, by means of the same terminology and laboratory practice, the whole community of expertises on air platforms wishes to execute investigations well reproducible and without technicians' clear mistakes and misunderstanding.

RTO AVT-137 co-operative Task Group has been working since 2005 in the framework of international cooperation between NATO countries, focusing on information exchange and sharing of maintenance data occurring on air platform fleets.

The participating countries in the Task Group are: Canada, Germany, Italy, Netherlands, United Kingdom and the United States.

Based on the experiences the author had while working at the IAF Flight Test Center through many failure Investigations, this work instruction is proposed as a setting of a general procedure to perform a failure investigation; terms and rules of the deliverable report and relative items are also discussed.

Both metallic and non-metallic materials undergo this work instruction.

5.1.1 Objective

A Failure Investigation is undertaken to determine the cause of a failure, and if possible, to identify corrective actions that should be initiated to prevent similar failures.

5.1.2 General Stages of an Analysis

The nature of the failure being investigated determines what steps and process must be employed. The following is a brief description of the typical stages of a Failure Investigation.

These are guidelines to be considered by the investigator; however, not every stage may be utilized.

5.2 PRELIMINARY DATA

Initially, the Failure Investigation should be directed towards gathering as much information relating to the failure insofar as to reconstructing its sequence of events.

This may involve obtaining materials specifications, drawings, and records as to the manufacturing, processing, and service history of the failed component or structure.

Eventually, health monitoring data regarding flight and land operations parameters could be useful during investigation.

5.3 LABORATORY STEPS

5.3.1 Photographic Records

It is important for the investigator to maintain a photographic record of the failed component (e.g. macroscopic, fractographs, micrographs, etc.) throughout the analysis to detail the characteristics of the failure.

This may initially be performed by the customer, investigator, or by an approved outside source.

5.3.2 Selection of Samples

It is critical that the investigator selects the correct components that accurately depict the failure. Sometimes, this may involve seeking other evidence of damage beyond the apparent failed component.

Also, ideally it would be beneficial to the Failure Investigation if a not failed same P/N component could be obtained for comparison.

5.3.3 Preliminary Examination of the Failed Component

Prior to cleaning, a record should be made to describe the “as-received” condition of the failed component. This is useful in determining the sequence of events leading to the failure. A thorough visual examination and record keeping are important to the Failure Investigation.

Visual inspection should be performed initially unaided and subsequently with photographic microscopes.

For fractured components, it is essential to document the entire component and then relate the fracture to the entire component.

5.3.4 Sample Handling and Operating

5.3.4.1 Preservation

The proper selection, preservation, and cleaning of fracture surfaces are critical to prevent important evidence from being destroyed or obscured. Fracture surfaces are prone to mechanical and/or chemical damage.

Surfaces of a fracture should never be touched by the fingers or be fitted together with the sections of a part. They should also be covered with a cloth or cotton during shipment and stored in a desiccator to prevent corrosion damage.

5.3.4.2 Cleaning

Fracture surfaces should only be cleaned when absolutely necessary, such as for electron microscope observation. Techniques employed are dry-air blast, ultrasonic cleaning with solvents or mild detergents, and application and stripping of plastic replicas.

For plastic materials, it is proposed to avoid organic solvents.

5.3.4.3 Sectioning

Due to the limit of size for testing and evaluation in equipment such as hardness testers and optical microscopes it may be necessary to excise a portion containing the fracture surface from the failed component. It is critical to keep an account of the sectioning with sketches or photographs. It is also important to preserve the fracture surface during cutting; application of a coolant or a secondary coating may be used.

5.3.4.4 Crack Opening

Primary cracks may need to be opened if they did not propagate to total fracture.

On the other hand, if the primary crack has been damaged or corroded such that the fracture surface has been obliterated, it is necessary to open any secondary cracks for examination and study. These cracks can provide more information since they are usually less damaged or corroded.

It is proposed to open cracks such that the two fracture surfaces move opposite to each other, normal to the fracture (crack) plane. If plausible, sometimes the use of a different fracture mechanism can be used to distinguish the secondary cracks from the primary.

It is also recommended that the crack length be measured prior to opening for fatigue fracture and strain analyses.

5.3.5 Non-Destructive Testing

Non-destructive testing can be useful in detecting surface cracks and discontinuities in a failed component.

Magnetic-particle inspection, liquid-penetrant inspection, eddy-current inspection, ultrasonic inspection, acoustic-emission inspection, and radiography are some of the commonly used techniques.

5.3.6 Mechanical Testing

Mechanical testing aids in the determination if the failed component conforms to specification or in evaluating the effects of surface conditions on mechanical properties.

5.3.6.1 Hardness

Hardness testing can be used to assist in evaluating heat treatment, providing an approximation of tensile strength, and to detect the work hardening or softening due to service/maintenance.

5.3.6.2 Tensile Strength and Toughness

Where appropriate, these tests should be performed only if sufficient material for fabrication of test specimen is available.

5.3.6.3 Dynamo-Mechanical Analysis

Where appropriate, these tests should be performed on plastic materials or polymer matrix composites only if sufficient material for fabrication of test specimen is available.

5.3.7 Chemical and Elemental Analysis

In a Failure Investigation, routine analysis is recommended to ensure that the material is one that was specified. Slight deviations in compositions are not likely responsible for failures. However, when considering failures due to corrosion or stress-corrosion, the analysis can be important in establishing the primary cause of failure.

It is worthwhile to determine elemental concentrations and to identify compounds in alloys, bulky deposits, and samples of environmental fluids, lubricants, and suspensions.

Various analytical techniques can be used in a failure investigation: emission spectroscopy, atomic absorption spectroscopy, inductively coupled plasma atomic emission spectroscopy, classical wet analytical chemistry, and spot tests. For surface constituents, compositions can be identified by energy-dispersive and wavelength-dispersive x-ray spectrometries.

Polymeric materials must be investigated for their chemical nature and both thermodynamic and kinetic parameters, by means of infrared spectroscopy, pyrolisis gas chromatography and thermal analysis.

5.3.8 Fractographic Examinations

5.3.8.1 Macroscopic Examination

The detailed examination of fracture surfaces at low magnifications (ranging from 1 to 100 X) may be done with the unaided eye, a hand lens, or a low-power optical microscope. The information obtained can give an indication of the stress system that produced the failure, the direction of crack growth and therefore the origin of the failure.

5.3.8.2 Microscopic Examination

Microscopic examination of fractured surfaces can be achieved with optical (light) and scanning electron microscopies. However, interpretation of the fractographs requires practice and an understanding of fracture mechanisms.

5.3.8.3 Microstructure Analysis

Metallographic examination of polished and polished-and-etched sections by optical microscopy and electron-optical techniques is a vital part of the failure investigation and should be conducted as a routine procedure. It provides the investigator with a good indication of the class of material involved and whether it has the desired structure. Information regarding to the method of manufacturing and heat treatment can also be obtained.

Metallurgical imperfections, i.e. inclusions and microstructural segregation in metals such as mislining of fibers and voids in polymer composites, can be detected and analyzed by microscopic examination. Other service effects such as corrosion, oxidation, and severe work hardening of surfaces, are also revealed, and their extent can be investigated.

In addition, important characteristics of the cracks can be identified, such as the mode of propagation.

5.3.9 Determination of Fracture Types

Examination of the failure region, the fracture surfaces, and metallographic sections, is necessary to identify the fracture type.

Fractures are usually classified in terms of their growth mechanism: ductile, brittle, intergranular, transgranular, and fatigue.

These mechanisms can be correlated with different modes of fracture, such as environment assisted failures (i.e. stress-corrosion cracking, melting, liquid-plastic deterioration, liquid-metal embrittlement, hydrogen embrittlement, and creep) and stress dominated ruptures (i.e. overload, wear, impact).

All these identifications aid to determine the cause of fracture.

5.3.10 Application of Simulation Tools

Finite Element Analysis (FEA) may be worthwhile in assessing how stresses act on failed part, by calculating the stress concentration factor (K_t) and residual fatigue life, either in presence or in absence of an existing crack or defect. Right material properties to be put in the calculation may be extracted both from references and mechanical tests.

5.3.11 Application of Fracture Mechanics Theories

The mechanics of fracture in metal parts and specimens under load have become increasingly important in failure investigations due to fracture and to the formulation of corrective measures that will prevent similar failures.

Fracture mechanics are useful in determining critical crack size and fracture stress (load). It can also provide a quantitative framework for evaluating structural reliability by means of NDT procedures, allowing maintenance to move to a “damage tolerant” approach of the cracked part.

5.3.12 Simulated-Service Testing

It may be necessary to conduct tests that attempt to simulate the conditions under which failure is believed to have occurred. Most of the metallurgical phenomena involved in failures can be satisfactorily reproduced on a laboratory scale, and the information derived from such experiments can be helpful to the investigator provided the limitations of the tests are fully understood. Furthermore, the simulated testing of the effects of certain selected variables encountered in service may be helpful in planning corrective action that will avoid similar failure or, at least, extend service life.

5.4 FINAL REPORT

5.4.1 Report Index

Failure Investigation final reports will include the following issues, not automatically in same sections or repeatable forms:

- Report and activity code;
- Object;

- Introduction;
- Selection of failed parts;
- Preliminary examinations;
- Fractographic examinations;
- Chemical analysis;
- Mechanical analysis;
- NDT (optional);
- Application of Simulation Tools (optional);
- Simulated-Service Testing (optional);
- Discussion on experimental results;
- Application of Fracture Mechanics Theories (optional);
- Determination of Fracture Types;
- Individuation of failure cause and chronological events;
- Conclusions;
- Recommendations (optional);
- References (optional); and
- Acknowledgements (optional).

Experimental procedures, tables and figures may be present in sections containing issues from 5.3.4. to 5.3.12. These sessions should also include a brief overview of the type of analysis performed and equipment used.

Some of these items are discussed in the following sections.

5.4.2 Object

It will indicate clearly vehicle and part gone under investigation. If needed, it will refer to customer statement.

5.4.3 Introduction

Presents the Statement of Work as tasked by the customer and the reason the customer requested the tests. It also identifies the customer.

The introduction should also include a “background” discussion, which will clearly relate the sample history.

5.4.4 Discussion on Experimental Results

Discuss the significance of the experimental results. Describe how the results apply to the statement of work and how they led to conclusions.

5.4.5 Conclusions

State the overall conclusion(s) of the Failure Investigation. These can be bulletized. Answer the question, “What did analyses tell us”.

5.4.6 Recommendations (Optional)

If recommendations (such as recommendations for further tests or maintenance procedures variation) are included in the Failure Investigation Report, they may be developed in conjunction between the Italian Air Force technicians and the Customer.

5.5 ROLES AND RESPONSIBILITIES

5.5.1 Department Manager

- Empowers personnel to perform Failure Investigations.
- Supports the required Failure Investigation/Materials Investigation Training needs.
- Stimulates inter-branch team work skills.
- Has familiarity with material characterization techniques.
- Signs Final Report.
- Archives copy of Final Report and retains copy.

5.5.2 Branch Head (Program Manager)

- Takes custody of Customer-Supplied Handbooks and official documents.
- Writes the activity proposal, pointing out laboratories/experimentations/tests/man hours needs.
- Individuates the Final report author.
- Notifies Author and Laboratories Managers via e-mail, lectures, phone calls.
- Proposes a Plan of Action and consults with other Department personnel.
- Writes internal work requests with Laboratory Managers.
- Solicits author for technical reviews of Final Report drafts.
- States closure of the failure investigation.
- Signs and submits the Final Report the Department Manager for signature.

5.5.3 Primary Laboratory Manager (Author)

- Takes custody of failed and not failed parts.
- Leads and executes the big part of experimental tests.
- Obtains all relevant information from experimental results.
- Notifies Branch Head and Laboratory Managers via e-mail, voice, phone calls.
- Determines required laboratory testing.
- Proposes a Plan of Action and consults with Branch Head and Laboratory Managers.
- Contacts Customer Engineers and/or consultants.
- Performs the monitoring of Internal Work requests with Laboratory Managers.

- Writes the Final Report drafts and ultimate version.
- Submits the Final Report to the Branch Head for review and signature.

5.5.4 Laboratory Managers

- Accept internal work requests from Program Manager.
- Complete laboratory experimentations.
- Generate Laboratory Reports and log-out documents to the Program Manager.
- Take custody of failed and unfailed parts during tests.
- Obtain all relevant information from experimental results.
- Notify Branch Head and Author via e-mail, voice, phone calls.