



HEALTH MONITORING OF AIRCRAFT

BY NONLINEAR ELASTIC WAVE SPECTROSCOPY

AERONEWS

EC SIXTH FRAMEWORK PROGRAMME

PRIORITY 4: AERONAUTICS AND SPACE

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Deliverable D23

Preparation of standardization

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1. Overview of the Tasks, Deliverables and Milestone of the WP6

Overall participants in WP5:

Workpackage leaders	ITASCR	
Person-months per participant:	4	

Participant id	KU Leuven	VUB	ASCO	DAKEL	VZLU
Person-months per participant:	3	1	1	3	1
Participant id	GIP-U	NDTE	IZPF	POLIT O	UNI-Na
Person-months per participant:	3.5	5	5.75	4	1.2
Participant id	CSIC	BR&TE	BODYC OTE	UNEXE	UNIV- BRIS
Person-months per participant:	1	0.5	0.9	1	1.5
Participant id	UNOTT	CU			
Person-months per participant:	1	1			

1.1 Overall objectives of WP6

- Spreading the knowledge on NEWS techniques throughout Europe and beyond
- Providing of efficient information exchange between AERONEWS partners
- Education of personnel at Universities and NDT-research centers
- Tentative design of standard recommendations for the use of NEWS techniques

1.2 Description of WP6 tasks

- WP6.1 Attend international conferences and publish results
- WP6.2 Organizing special sessions devoted to NEWS at national and international NDT meetings and exhibitions.
- WP6.3 Write publications in international journals publication process in international reviewed journals.
- WP6.4 Create an information leaflet and maintain a web-page with project objectives and achievements.
- WP6.5 Document the specific requirements concerning NEWS application in aeronautical NDI
- WP6.6 Organize specialized university classes and prepare the implementation of NEWS methodology to NDT personnel education and qualification courses
- WP6.7 Promote the test device system

- Wp6.8 Prepare preliminary standard practices on NEWS methodology

1.3 Deliverables, Milestone and expected result of WP5

- D22. Papers, web-page, conference contributions, workshops, propotion folders, educational courses, and users manual for NEWS application
 - Delivery date: month 12, 24, 36, 48
- D23. Preparation for standardization.
 - Delivery date: month 48

Preparation of Standardization

1. INTRODUCTION

Deliverable 23 is part of Work Package 6 “Dissemination and Training activities”. Part of the activities of the consortium in this Work Package has been oriented to the dissemination of scientific results, both by attending national and international conferences and by publishing in national and international journals. In several occasions, special sessions have also been prepared to explain the results of the research in international NDT and SHM meetings. Exhibitions and University classes and courses have been also organized. In addition, this Work Package also focuses on studying the possibility of suggesting nonlinear techniques as a standardized tool for damage detection.

The existing *Nondestructive Evaluation Technologies* are rather mature. During many years they have seen a significant growth and have a widespread use and acceptance throughout many industries, including aerospace. Nondestructive technologies are able to detect damage with considerable reliability during maintenance inspections. *Structural Health Monitoring* is still an emerging technology that has demonstrated great potential for the fact of using on-board damage detection sensors and systems. Both possibilities (NDT and SHM) have been analyzed during the AERONEWS project for the nonlinear techniques studied.

During the last General Assembly and Technical Meeting in Toulouse (France), the consortium discussed the elementary steps toward standardization for the techniques and methods developed during the project. More tests on a larger amount of samples will be needed to confirm the present results and to present the nonlinear techniques as “standarizable” methods. However, as well as we discussed in D20-21, the experimentation carried out during all the years, the variety of methods, sensor technologies, procedures, etc., have established a good foundation for future standardized techniques. Nonlinear methods are foreseen both as potential Nondestructive inspection

of damage, and as future Structural Health Monitoring systems. As NDT, nonlinear methods would be more universal, while SHM systems are structure dependant.

Nondestructive Techniques have been in place during many years and the procedures for standardization are well established. After this introduction, the next section of this deliverable presents the general lines that define a standardization process for NDT. It explains which committees are responsible of NonDestructive Evaluation techniques, which already existing standards must be taken as reference, and finally the main elements that a new standard about nonlinear techniques would contain. An example with the general outline of a standard is also presented.

The SHM case is somehow different. SHM systems are inspection methods permanently installed as integrated part of an aircraft. After many years of studies, some SHM technologies start to have an industrial application. In order to be part both of the aircraft structure and of the maintenance process of an aircraft, it is needed to have rules and standards that regulate them. However, until now, those standards do not exist. There are no specific rules, standards or specific requirements that must be followed in order to fully integrate an inspection system as a technique fully integrated in the aircraft. The last section of this deliverable analyses this aspect. It also analyses which of the existing standards that could be applied to the AERONEWS nonlinear methods as potential SHM systems. This section also describes some topics that should be covered by future SHM standards. This section also comments the recent creation of a new specific Committee with the goal of regulating emerging SHM systems using nonlinear methods. Manufacturers, academy, industry, etc. are represented in that Committee.

2. STANDARDIZATION OF NON DESTRUCTIVE TESTING

2.1. STANDARDIZATION OF NON DESTRUCTIVE TESTING – WHO IS DOING WHAT

The European standards that are in use have to be approved by CEN (European Committee for Standardization). The members of the CEN are the representatives of the national board of each European country.

Most of those documents have been drawn up in technical committees. The technical committee in charge of non destructive testing technics is the CEN/TC138 group. CEN/TC138 is responsible for the preparation of European standards on:

- qualification and certification of personnel,
- NDT concerning RT, UT, ET, PT, MT, LT, VT, X-ray powder diffraction.

For each method, the technical committee is able to work on the:

- **Terminology**, with the objective of defining the common language of the NDT community.
- **General principles**, to define and clarify NDT methods by the formalisation of the rules of the art.
- **Verification of equipment**, with the goal of harmonizing the methods of characterization, putting in parallel the performance and the expected quality of tests.

Most of the time, some preliminary work has first been launched by groups of NDT users, in the frame of their national board (e.g. COFREND in France, AEND in Spain, BANT in Belgium, DGZfP in Germany, AIPnD in Italy, BiNDT in UK....)

2.2. ELEMENTS OF NDT QUALIFICATIONS ACCORDING TO CEN/TR14748 DOCUMENT

A document describing the methodology for qualification of non-destructive tests has been issued from CEN/TC138 technical committee end of year 2004 (Ref.[1]).

Qualification of a non destructive test may be necessary in the case of non-standardised NDT or if the NDT does not fully comply with the appropriate standard. The objective of qualification is to provide confidence in the test itself and also in its

continued performance. Qualification should also be considered when there are reasons to provide additional assurance that NDT can meet the inspection requirements.

The objective of the qualification process is to determine whether the technique is capable of attaining their objectives. It applies to all aspects of tests which influence their effectiveness.

The qualification should consist of one the following items:

- Practical assessment (blind or open trial) conducted on the component to be inspected or on representative test pieces.
- Technical justification, which gives all evidence of effectiveness of the test. Previous experience of its application, experimental studies, mathematical modelling and physical reasoning could be included.
- Appropriate mix of practical assessment and technical justification.

The normative document is stating that in some cases, it may be possible to qualify NDT without any practical trials.

The normative CEN/TR 14748 document is giving a list of the qualification phases and steps as follows:

- **Phase 1 - prior to NDT qualification.** Before starting the qualification process, the following input data should be made available:
 - Objectives, description of what the qualification is intended to achieve
 - Field of application (for example aeronautic, oil industry ...)
 - Description of the component to be tested.
 - Site conditions/environmental considerations (at manufacturing stage or in service for example), access limitations.
 - Type, dimensions, orientation of discontinuities to be detected.
 - The required performance of the non destructive test to be evaluated (detection, characterization, sizing and position).
 - Identification of the qualification team
 - Documents related to the technical justification
 - A draft NDT procedure, which should describe equipment and personnel requirements.
 - Time scale for the qualification process.

- **Phase 2 - Planning of NDT qualification.** A qualification program which describes how qualification will be implemented , is produced:
 - Objectives of the NDT qualification.
 - The way the technical justification and NDT procedure will be assessed.
 - Details on how any practical trials will be conducted.
 - Details and availability of qualification test pieces.
 - The way the results of the qualification will be evaluated;
 - The issuing of a qualification dossier and relevant statements.
- **Phase 3 - conducting NDT qualification:**
 - The **qualification team** assesses a draft NDT procedure that identifies the essential parameters and specifies allowable equipment parameters. The qualification team determines the extent of any open/blind test piece trials; they are responsible for the identification and design of the test pieces and their fabrication.
 - **Test pieces:** Sufficient test pieces and/or available components containing real discontinuities should be made available in order to enable the draft NDT procedure and equipment to be qualified. A blind trial, if performed can be a realistic way of assessing the performances of the combined personnel, equipment and procedure. The qualification team needs to be aware of the actual defect type, dimensions, orientation and position within the qualification set of test parts. These parameters can be established by destructive examination, by control of the test piece manufacturing process or through confirmation by alternative NDT method.
 - **The qualification dossier** is archived and remains accessible if required. That dossier contains all information related to the whole process of NDT qualification (input information, draft procedure, technical justification, qualification programme, test reports, identification of the equipment used for the qualification, conclusions of the qualification including results of all assessments and practical trials, qualified procedure).

- **Phase 4 - Acceptance/ rejection of NDT qualification:**
 - When NDT qualification has been successful, the statement issued from the qualification team has to identify the NDT procedure and/or equipment which were used for qualification. Qualification statements remain valid until essential changes are made to the procedures, equipment, code or standards.
- **Phase 5 - Implementation of qualified NDT:** Based on the results of the qualification, a qualified NDT procedure is established or confirmed and is added to the qualification dossier.

Results from AERONEWS project could be used as a basis for the technical justification of the qualification process. Some examples of recommendations are also regarding nonlinear techniques are also reported in D20-D21. The writing of a draft procedure and the description of a test protocol would be required in order to perform the practical qualification of the procedure on several test parts.

2.3. *STANDARDS IN USE FOR AERONAUTICAL NDT METHODS*

NDT methods in aeronautics but also in other industries are used in the frame of several standards covering the following topics:

- Personnel: Qualification and approval of personnel for non destructive testing;
- Terminology
- Equipment: characterization and verification;
- Calibration blocks: Specifications which are particularly highly required for nonlinear measurements
- General principles to perform NDT using a specific technique and rules for inspecting specific materials and/or geometry;

2.3.1. *Qualification and approval of personnel*

Non destructive inspection for aeronautics can only be performed by personally qualified and approved according to NAS410 or EN4179 standards. These standards establish the minimum requirements for the qualification and certification of personnel in non destructive testing (NDT). These requirements include training,

experience and examinations for personnel performing NDT in the aerospace manufacturing, service, maintenance and overhaul industries.

This standard applies to personnel using NDT methods to test and/or accept materials, products, components, assemblies or sub-assemblies. It also applies to those individuals directly responsible for the technical adequacy of the NDT methods used, as well as personnel performing external NDT technical audits or providing technical NDT training.

These standards contain detailed requirements for the applicable training, experience and examination for the following common NDT methods:

- Liquid penetrant (PT)
- Magnetic particle (MT)
- Eddy current (ET)
- Ultrasonic (UT)
- Radiography (RT)

These standards may apply to other NDT methods that can be used to determine the acceptability or suitability of a material, part, component, sub-assembly or assembly. Such methods include, but are not limited to, acoustic emission, neutron radiography, penetrant leak testing, thermography, holography, and computed tomography. The requirements for personnel training, experience, and examination for these other methods shall be as established by the cognizant NDT organization and shall be in accordance with the guidelines established for the common methods.

Each method is split into several techniques. For example training and certification related to ultrasonic (UT) method is covering, pulse echo as well as transmission technique, thickness measurement, resonance, pitch catch inspection using surface or lamb waves and phased array.

The NEWS techniques that are only using ultrasonic probes with specific acquisition setup and specific Ascan data treatment could probably be included as a technique into the ultrasonic method. The NEWS techniques using laser generation or vibrometer detection would probably lead to the need for the definition of a new specific sub-method inside the UT method

In any case a training program should be built with the aim to provide background information such as origin of the nonlinear response in the material, specifications for probes and setup, typical signals or data coming from a defective area. This training

program can be also useful for other NDT methods which can be also linked to nonlinear treatment (RT, ET or MT)

2.3.2. Terminology

The terms used in ultrasonic and their definition are given in the EN1330-4 normative document. The terms used in Acoustic Emission and their definition are given in the EN1330-9 normative document.

A list of terms specific to nonlinear elastic Waves techniques should be built with their associated definition. The document then would have to be transmitted to CEN/TC-138 working group that has the decision to launch a work item.

2.3.3. Equipment characterization and periodic verification

Several normative documents apply to the equipments used in conventional ultrasonic inspection.

EN12668-1 document specifies the procedures and acceptance criteria that have to be used to assess the electrical performances of ultrasonic examination devices using pulsed excitation and Ascan display of the data. This document specifies the tests that have to be performed by the manufacturer on new equipments, but also tests that have to be performed periodically (once a year) to ensure satisfactory performances.

EN12668-2 document specifies procedure and acceptance criteria that have to be used by manufacturer to assess the probe performances.

EN12668-3 document describes the method and specifies the acceptance criteria allowing to check the operating performance of the ultrasonic device combined with the probe, by means of the appropriate calibration block.

Those documents can not be applied directly to the nonlinear techniques developed in AERONEWS project. Equipments used for NEWS techniques are specific in terms of excitation strategies and in terms of data exploitation. Intrinsic characteristics that have an influence on detection and/or sizing performances and that could be subject to degradation have to be identified. Special attention must be carried out relatively to the amplitude (or power) of excitation strategies.

2.3.4. Calibration blocks: Specifications;

The **EN12223** document specifies the material, the dimensions and the manufacturing process for calibration block that will be used to calibrate instrument and probe setup for manual inspection. Those blocks are used to check that the combination of device and probe is able to perform the inspection. Those blocks are including reflectors such as EDM notches, flat bottom holes, side drilled holes. Blocks with artificial defects are suitable for the calibration of conventional ultrasonic techniques but those blocks will not be useable for NEWS techniques because none of these reflectors is able to introduce any nonlinearity effect into the ultrasonic response.

For NEWS techniques, specific calibration blocks and procedure will have to be defined with the purpose of ensuring a known level of nonlinearity (like fused-silica) that will then be measured by the equipment setup, and the experimental conditions that have to be calibrated.

2.3.5. General principles and rules for inspecting specific materials and/or geometry

Each NDT technique is linked to a normative document dealing with the general principles required to perform the testing of the structures with the purpose of providing clear and reproducible results. This kind of document contains guidelines for preparing application documents that describe the specific conditions required to apply the NDT method.

For conventional NDT methods, we can find several normative documents dealing with their application to specific materials or geometry, giving information regarding the required setup and criteria for detection and/or sizing of defects.

The writing of a normative document describing the general rules of NEWS technique as a non destructive method would require the description of at least the following chapters:

- Principle of NEWS technique
- Advantages and features of NEWS technique
- Limitations of NEWS technique
- Applications (phase of the product life, structures and materials that can be addressed)
- Instrumentation (sensors, device, signal conditioning and processing, settings)

- Examination (preparation of the part, data acquisition).
- Data analysis
- Examination procedure
- Examination report.

2.3.6. Possible structure of a new standard

Taking into account the all the aspects covered in the previous sections, a new standard related to the application of NEWS techniques could have the following structure:

1. Scope

2. Normative references

EN 1330-1:1998, *Non destructive testing - Terminology - Part 1: List of general terms*

EN 1330-2:1998, *Non destructive testing - Terminology - Part 2: Terms common to the NDT methods*

EN 1330-9:2000, *Non-destructive testing - Terminology.*

3. Terms and definitions

4. Personnel qualifications

5. General

- 5.1. The structure part or material to be tested
- 5.2. The nature of the failure to be detected
- 5.3. Threshold of detectability
- 5.4. Requirements of the equipment needed
 - 5.4.1. Sensors and actuators
 - 5.4.2. Generators and their associated excitation strategies
 - 5.4.3. Signal recorders
 - 5.4.4. Multiplexer
- 5.5. Variables that can affect the measurement
 - 5.5.1 Noise
 - 5.5.2 External nonlinearities

6. Calibration techniques for

- 6.1 Generators and their associated excitation strategies
- 6.2 Sensors nonlinear response
- 6.3 Receivers and their intrinsic nonlinearities

7. Measurement conditions

8. Testing

- 8.1. Pre-Test Measurements
 - 8.1.1. Wave propagation
 - 8.1.2. Sensor and actuator placement
- 8.2. Test steps
 - 8.2.1. General Guidelines
 - 8.2.2. Background Noise
 - 8.2.3. In situ verification

9. Analysis of results

10. Documentation

The final report should include the following:

- a) test instruction and revision no.;
- b) name(s) of test operator(s);
- c) date and place of the test site;
- d) type of instrumentation; coupling and frequency characteristics of sensors and actuators,
- e) drawing with dimensions showing sensor and actuator locations;
- f) results of system verifications;
- g) used interrogation frequencies, amplitudes and measurement conditions;
- h) results of attenuation and wave transfer measurement;
- i) description of the maximum nonlinearity zones with the classification obtained from the evaluation criteria

The report should be in accordance with EN ISO/IEC 17025 (paragraph: reporting).

Zone severity grading definition and further actions recommended

- A Very low or no nonlinearity detected
- B Low nonlinearity zones detected
- C Medium nonlinearity Follow up with other NDT
- D High nonlinearity Follow up with extensive NDT of detected zones

11. Bibliography

References to other standards used

2.4. PROBABILITY OF DETECTION STUDIES (POD)

For new methods or new techniques on specific NDT tasks, qualification test program has to be performed (several parts, different defect size, several operators). Main objectives of those test campaign are to prove the capability of the technique to detect defects as well as to assess the limitations.

Probability of detection (POD) study is a standard method for quantitative NDT process capabilities assessment. It will result in an evaluation of the reliability and an evaluation of the minimum detectable size with its level of confidence.

POD studies have mostly been performed in metallic parts; the following parameters are to be considered:

- Several real fatigue cracks of different size and undamaged part.
- Several inspectors to apply the NDT technique on the full set of part / round robin tests.
- Destructive testing of the parts to find out the actual dimensions of the crack.
- Analysis of the set of data :
- Plot the result of detection as a function of crack size.
- Number of false calls

A POD curve is dependant on the test object, the material, the defect condition, the NDT procedure and the operators. The first step is to verify the evidence of nonlinear signature by changing the amplitude (or power) of the excitation procedure (deviation of linear properties which have to be also well defined) which are very specific to the nonlinear method and not present in standard other NDT techniques. This kind of study is the only way to assess the detection capability of the technique associated with its level of confidence.

The qualification of Non Linear Elastic Waves Spectroscopy (NEWS) technique to be applied in aerospace industry would require a POD study. As NEWS techniques, in some cases will be more sensitive than conventional methods, arises the question of how to standardize a technique when you do not have another method to assess. A good answer is probably, the POD study followed by a destructive testing of the parts at the end to compare NEWS detection and/or sizing results with actual damage characteristics.

2.5. *THE EXAMPLE OF THE QUALIFICATION OF TOFD TECHNIQUE*

The TOFDPROOF project was a pre-normative research project aimed at producing a coherent package of guidelines and procedures for applying TOFD (Time of Flight Diffraction) with related acceptance criteria and recommendation for training and certification, based on a European wide inter-laboratory testing program. This project was held between years 2002 and 2005.

The project was focused on all aspects allowing the effective application of the TOFD as a stand alone method for the weld inspection during manufacture of pressure equipment. Technological, regulatory, human factors were considered. The performance of TOFD was compared with conventional NDT as defined by European standards for testing pressure vessels at manufacturing stage. This evaluation was carried out by means of a round robin test on welded specimens. 150 weld defects were collected. The blind trials required 961 tests covering all NDT methods, of which 395 TOFD testing.

Results generated by this round robin exercise were put in a suitable form for implementation in CEN standards and dissemination among NDT specialists. Recommendations for training and certification of personal were written and distributed to the NDT society, the relevant standardization CEN technical committees and the EU companies dealing with weld inspection.

The example of qualification of the TOFD technique is interesting when asking the question of the qualification of a new NDT technique. TOFD was originally developed as a method of accurately sizing and monitoring the through-wall extent of welding defects and in-service flaws, primarily in steel components. Maurice Silk, its inventor, released the first report for publication in 1974, stating the main principles of the technique. Since then a lot of feasibility studies have been performed on different kind of parts and defect location so that a lot of experimental results were available, showing the capability of the technique. It took more than 30 years from the first publications to the standardization. Another comment regarding TOFDPROOF is that they focused on only one specific application of the technique (e.g. inspection of weld in pressure equipments).

Considering the results of AERONEWS project, we can conclude that the timeline to achieve qualification of the NEWS technique is still long. Some results are promising but we are not yet at a point where this method can go to standardization. A way to reach that point could be, first to identify a specific application, then to make a selection of the best suited nonlinear technique and then consider round robin trials to assess the capabilities and the limitations of the technique.

3. STANDARDIZATION OF STRUCTURAL HEALTH MONITORING SYSTEMS

Structural Health Monitoring is a relatively new concept in aviation. The current developments in SHM still need to prove commercial implementation. There is a growing demand from the aerospace sector, both in government and private industry, for standardized procedures and implementation of SHM technologies. They want to promote industrywide cooperation on the use and development of SHM. But, for the time being no specific standards defining requirements for SHM systems have been created.

However things have started to move forward. It was during the 3rd European Workshop on Structural Health Monitoring (held in Granada, Spain, in July, 2006) when government and industry representatives expressed the need for creating industry-wide policies and procedures for the standardization and implementation of SHM technologies. In that moment, workshop participants asked Fu-Kuo Chang, Professor of Aeronautics and Astronautics at Stanford University, to create the Structural Health Monitoring - Aerospace Industry Steering Committee (SHM-AISC). Some months later, the newly created Committee held its first meeting.

The international management board comprises representatives from major aerospace industries from across the globe (Airbus, Boeing, EADS, Embraer, Honeywell, BAE system), regulatory agencies from the United States and Europe (FAA/EASA), the government agencies (US Air Force, US Army, ATA and NASA), Research and Development institutions (Sandia National Labs, Stanford University, University of Tokyo). In the first meeting that took place at Stanford on 7 November 2006, Prof. Chang was elected to be the first chair.

As Prof. Chang declared “The aim of the SHM-AISC is to formulate a collective view of the way forward for the practice of Structural Health Monitoring (SHM) and its impact on the management of structural health. The group will plot a course to efficiently and effectively implement the technology in a wide variety of commercial and military aerospace applications. This will be achieved by the development of standards, procedures, processes and guidelines for implementation and certification. The mission of

the SHM AISC is to provide an approach for standardizing integration and certification requirements for SHM of Aerospace structures, which will include system maturation, maintenance, supportability, upgrades and expansion. The final goals will be to develop a guidebook specifying approach for SHM usage on Air and Space vehicles and to identify technology gaps leading to SHM utilization”.

The SHM-AISC will have three working groups: Commercial Aviation, Military Aviation and Aerospace. The committee's working groups will develop standards, procedures, processes and guidelines for SHM implementation and certification. The first Working Group, Commercial Aviation, was established at the beginning of 2007. It was expected that it would produce the first draft standards in the following two years.

In this Deliverable, based on the experienced acquired during the Aeronews project, general ideas for standards that can affect any type of SHM system to be installed inside an aircraft have been identified.

3.1. ISSUES FOR SPECIFIC STANDARDS ABOUT SHM SYSTEMS

There are some existing standards that provide some framework for installing new monitoring systems inside an aircraft, however, it is necessary to create new standards that cover specific aspects of this type of systems.

Some of the aspects that those specific standards should cover are related with design criteria: allowed weight and size, connections with other systems in the aircraft, power supply systems, additional tests in the aircraft structure when the sensor are either fixed or embedded. Another important aspect to be covered by these future SHM systems are related to environmental working conditions of the systems, the reliability of the data and results extracted, the durability, etc.

Maybe some of the aspects covered by these standards should contain some differences if the systems are to be installed in:

- existing vehicles to monitor damage growth

- new vehicles. In this case, the SHM system should be integrated in the design from the beginning.

Robustness and reliability of the system

It is needed that new standards validate also the robustness of the SHM systems. The sensors must be sufficiently robust so as not to require replacement within the life of the components that is being monitored.

In order to have a correct diagnosis of the state of the structure, the signal received by the sensors has to be reliable. The signal can be affected by the operational conditions, both environmental and loading. It is necessary to avoid false negative and false positive results. Appropriate tests must be designed.

Aircraft Inspection and Maintenance

SHM systems represent a change in the current maintenance philosophy. How to integrate SHM system in the maintenance process, or the changes in the inspection processes could be considered by new standards

Maintenance of the SHM system: If one of the primary goals of SHM is to increase the service life of the structure or part being monitored, it is of great importance to analyze how the inserted, embedded or attached sensor can impact the performance and the life of the part. The installation of sensors (and all the corresponding wiring) is also influencing the way the part must be inspected and maintained.

Structural integrity

It must be studied that the sensors and the wires or any additional equipment do not affect the integrity of the structures being monitored. The structure must show the same stiffness, strength and fatigue life with and without the sensors installed. The structural integrity might be covered by the current standard RCTA/DO-160E.

3.2. *CURRENT STANDARDS THAT CAN BE APPLIED TO SHM SYSTEMS.*

As it was explained at the beginning of this section, for the time being, there are not specific standards for SHM systems. In this moment, SHM system could at least follow the existing standards related to environmental conditions and structural design.

3.2.1. *Environmental standards*

An important set of standards refer to the environmental susceptibility of the system. SHM devices will have to withstand harsh in flight environments during operational conditions that can affect their performance as well as their durability. For example, actuators and sensors are a key point of monitoring systems. It must be taken into account that they must endure millions of cycles, so mechanical fatigue of these actuator elements must be taken into consideration.

- RTCA/DO-160E “*Environmental Conditions and Test Procedures for Airborne Equipment*”. This document is issued by the Radio Technical Commission for Aeronautics. It is recommended by the Federal Aviation Regulations (AC21-16D) to show compliances with appropriate airworthiness requirements. This standard is used as a standard for environmental testing since 1958. It defines procedures to test airborne equipment for aircraft ranging from light aircraft to large commercial jets. The corresponding International Standard is ISO – 7137.

Main aspects covered by RTCA/DO 160 E are:

Temperature

Pressure

Moisture

Fluid susceptibility

Vibration

Acceleration

EMI susceptibility and emissions (Electromagnetic compatibility)

- MIL-STD-810 “*Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests*”.

It was first released in 1959 and it provides guidance for similar tests as those included in RCTA/DO 160 E, but adapted to military applications. It includes several shock and vibration conditions only normally found in military applications as ballistic, pyro and tethered landing shock.

- MIL-STD-461E. “*Department of Defense Interface Standard Requirements for the Control of Electromagnetic Interference Characteristics of Equipment*”. This standard includes the Electromagnetic tests not included in the previous standard. The test protocols are designed for evaluating conducted and radiated emissions from electronic components. It also quantifies their susceptibility to electromagnetic interference.

3.2.2. Structural Design standards

- FAR 25. It describes design criteria for major aircraft components; however, there are not specific standards that cover mechanical SHM design criteria, for example, for sensors or actuators bonded to structures or components.

4. SUMMARY

Even though the process would still be long, it is foreseen that Nonlinear methods have a potential to become part of the NDT methods in the aeronautical industry. This document has described the existing procedures for qualification and standardization of NDT methods and the way the nonlinear methods studied during Aeronews would be integrated in the process. The future implementation of NEWS as SHM systems is not excluded. In the absence of existing documents and established procedures about the implementation of SHM systems, this document has also given a general view of fundamental aspects that should be considered in the future.