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To link to this article: DOI:10.1016/j.aei.2012.06.006
http://dx.doi.org/10.1016/j.aei.2012.06.006

To cite this version:

Kamsu Foguem, Bernard *Knowledge-based support in Non-Destructive Testing for health monitoring of aircraft structures.* (2012) Advanced Engineering Informatics, vol. 26 (n° 4). pp. 859-869. ISSN 1474-0346

Knowledge-based support in Non-Destructive Testing for health monitoring of aircraft structures ☆

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Keywords:
Experienced knowledge
Formal visual reasoning
Conceptual graphs
Non-Destructive Testing
Maintenance procedure
Aircraft industry

A B S T R A C T

Maintenance manuals include general methods and procedures for industrial maintenance and they contain information about principles of maintenance methods. Particularly, Non-Destructive Testing (NDT) methods are important for the detection of aeronautical defects and they can be used for various kinds of material and in different environments. Conventional non-destructive evaluation inspections are done at periodic maintenance checks. Usually, the list of tools used in a maintenance program is simply located in the introduction of manuals, without any precision as regards to their characteristics, except for a short description of the manufacturer and tasks in which they are employed. Improving the identification concepts of the maintenance tools is needed to manage the set of equipments and establish a system of equivalence: it is necessary to have a consistent maintenance conceptualization, flexible enough to fit all current equipment, but also all those likely to be added/used in the future. Our contribution is related to the formal specification of the system of functional equivalences that can facilitate the maintenance activities with means to determine whether a tool can be substituted for another by observing their key parameters in the identified characteristics. Reasoning mechanisms of conceptual graphs constitute the baseline elements to measure the fit or unfit between an equipment model and a maintenance activity model. Graph operations are used for processing answers to a query and this graph-based approach to the search method is in-line with the logical view of information retrieval. The methodology described supports knowledge formalization and capitalization of experienced NDT practitioners. As a result, it enables the selection of a NDT technique and outlines its capabilities with acceptable alternatives.

1. Introduction

Certification authorities require that exposed aircraft components must be tested to prove their impact-resistant structure. The destructive and semi destructive methods (e.g. sectioning, contour, hole-drilling, ring-core and deep-hole) rely on the measurement of parameters (e.g. deformations) due to the release of actions (e.g. residual stresses) upon removal of material from the specimen. The non-destructive methods (e.g. X-ray, ultrasonic and magnetic methods) typically measure some parameters that are related to the assessment of component-inspected damage, without removing material [1]. Non-Destructive Testing (NDT) methods for assessing the integrity of an aircraft structure are essential to both improve reliability and availability of aircraft due to maintenance [2]. NDT techniques provide fitting inspection and evaluation means that can be used to monitor the compliance of airworthiness requirements for civil aircraft structures [3]. They for the assessment of fatigue related damage become increasingly significant, since many structural components need to be inspected periodically to prevent major damage or even failure [4]. These techniques usually measure some parameters that are related to the stress, in order to detect service failures in aircraft components, which occur by fatigue [5]. Predominantly, a key concern with ageing aircraft is the deterioration of structural components in the form of fatigue cracks at fastener holes, loose rivets and disbonding of joints [6]. The failures are revealed during regular control by the maintenance unit for non-destructive examination. The maintenance service aims to define the methods of maintenance of equipment in an ongoing effort to improve the quality and cost. Among other things, they must address the demands of the workshop (document changes such as Component Maintenance Manual (CMM)/Equipment Maintenance Manual), to improve methods and processes. CMM is a document issued by the manufacturer of the equipment, which allows for the complete maintenance of the equipment. Maintenance operations in aeronautics aim to guarantee the aircraft performance, its availability and airworthiness. Particularly, these operations can identify the locations and reasons for failure during high energy impact to simple aircraft structures. In order to improve maintenance processes, it can be used to create parts lists that will belong to the kits (parts list to

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resolve technical problems) based on equipment failure. The implementation of these kits is useful for improving common templates in the industrial maintenance. To enable this development, the creation of electronic records management is required. Appropriate identification of aircraft maintenance equipments is a challenge, as aircraft configurations change depending on assignments and maintenance procedures. Aeronautical maintenance relies upon a multifaceted system based on functional and safety requirements, test methods and continuous improvement. Support contracts imply certain collaborations between customer premises, supplier OEM (Original Equipment Manufacturer) and subsidiaries premises. This maintenance can be carried out from the simple level to a more complex level [7]. At the simple maintenance level, actions require either simple procedures or the use of easily employed maintenance equipment. This type of action is performed by qualified personnel following the detailed procedures and using the equipment specified in the maintenance instructions (e.g. checking parameters on a piece in use, simple adjustments (alignment, change of settings, etc.)). At the complex maintenance level, activities require the know-how based on the mastery of highly specialized techniques or technologies. By definition, this type of maintenance operation (overhaul, reconstruction, etc.) is carried out by the manufacturer or by a specialized service or company familiar with the manufacture of the equipment and using maintenance equipment defined by the manufacturer (e.g. general overhaul with complete dismantling of the engine, dimensional and geometric repair, major repairs or restoration carried out by the manufacturer, etc.).

In this paper, we discuss how formal semantics representations can be applied profitably to tackle the problems of formal specification of technical resources of maintenance procedures with visual reasoning mechanisms in industrial maintenance management. As an application example, we focus on a formal conceptual modelling of technical resources used in maintenance procedures of Non-Destructive Testing in aircraft industry applications.

The paper is organized as follows: Section 2 presents a literature review about Non-Destructive Testing methods for aircraft structures and introduces the principles of information structuring for maintenance equipments. The conceptual graphs formalism used throughout our work is detailed (formal semantics and reasoning constructs) in Section 3. Section 4 states how to apply the formalization approach in the context of equipments management for Non-Destructive Testing procedures in aircraft industry applications. Section 5 presents concluding remarks about the proposed approach to improve domain knowledge formalization from conceptual modelling to requirements specification.

2. Information management in structural health monitoring

2.1. State-of-the art Non-Destructive Testing methods

Failures of different aircraft components are revealed and examined generally by the use of non-destructive examination methods. The NDT methods can reliably detect and locate defects having dimensions well below those, which could impair the thermal fatigue lifetime. For instance, Non-Destructive Testing (NDT) methods that visualize the propagation of ultrasonic waves in solids are applicable to inspections of composite structures for disbonding detections [8]. These methods are also applied to detect fretting damage on the faying surfaces of intact specimens representing aircraft fuselage joint construction [9].

We chose to create a hierarchy of domain concepts, establishing a tree with four levels, from general to specific. The idea is to ensure that equipment has a unique code, while a code may contain several pieces of equipment (see Fig. 1). For example, EPH-GDAE: Eddy Current Probe for High Frequency Eddy Current and Use Standard/ Geometry 45° + Angle Tip-Shielded/ Frequency 500kHz.

2.1.1. First-conceptual description: General methods

For instance, ultrasonic inspection of materials offers interesting possibilities for the development of in-line Non-Destructive Testing (NDT) systems. Depending on the configuration, one or more ultrasonic images of the defect can be observed, their number and relative position containing information about the location of the defect. More commonly, these methods are eight in number:

- Visual inspection.
- Optical methods.

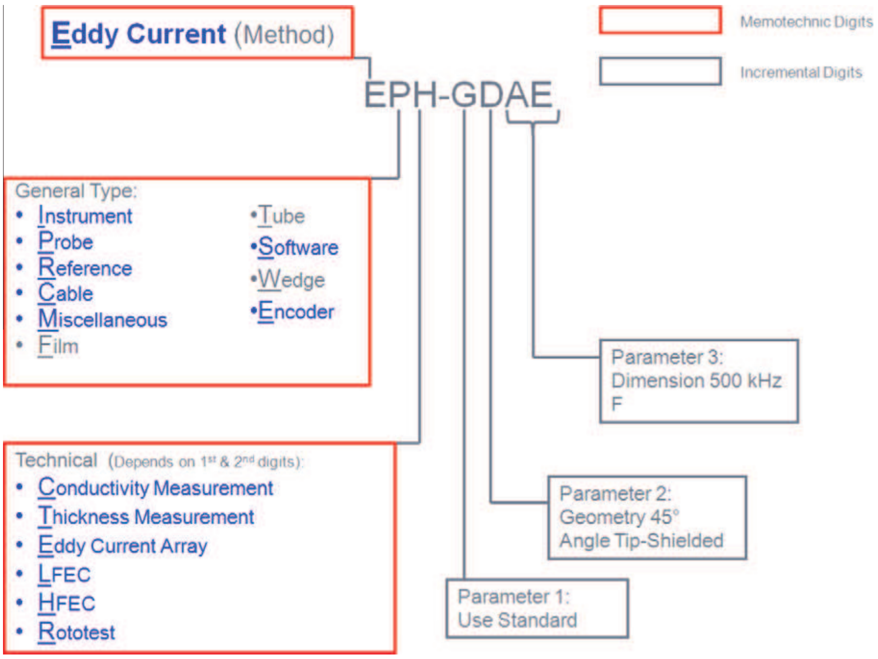

Fig. 1. An example of equipment codification (courtesy of Airbus S.A.S).

- Eddy-current (electro-magnetic testing).
- Ultrasonic inspection (including Laser ultrasonics).
- Acoustic emission.
- Vibration analysis.
- Radiography.
- Thermography.

These methods are effective to evaluate various defects and/or subsurface features on aerospace composites and aircraft metallic structures. They have been used in a variety of applications, i.e. inspection of subsurface defects and features, identification of thermo-physical properties, detection of coating thickness and hidden structures. We are inspired by the review found in [4] for a description of currently used NDT methods as follows:

Visual inspection confines itself to the detection of flaws located proximate to the surface. The techniques of impact sensitive coatings, liquid penetrants and magnetic particles are used to enhance the sensitivity and resolution of the inspection.

Optical methods contain photoelasticity, holography, Shearography and Moire methods that recognize material changes based on variations in transmission intensities, and phase changes, diffraction properties and interference fringe patterns. In particular, Shearography has advantages in terms of the large area testing capabilities (up to 1 m^2 per minute), the non-contact properties, the insensitivity to environmental disturbances, and the good performance on honeycomb materials.

Eddy current testing is an electromagnetic method carried out as a routine depot maintenance procedure to examine the condition of the structures for surface and around surface cracks, corrosion, delaminations and other structural defects (e.g., the state of the inner wing weep holes). Of course, it is advisable that such a smart eddy current NDT system is complemented by strictly optimized machine settings including finite element method for analysis of the inductive field caused by the eddy current sensor [10].

Ultrasonic inspection employs concentrated high energy acoustic waves to pinpoint flaw existence and flaw dimensions, determine geometric dimensions and characterize material properties. Applications include impact damage detection and location in composite beams and Crack Detection in repaired metallic structures. Also, it is applied to detect fatigue damage in carbon-fibre-reinforced epoxy (CFRP) composites used in aircraft structures. *Laser ultrasonic* offers the flexibility of testing structures with complex curvatures as the probe does not have to be normal to the surface.

Acoustic emission (AE) detects movement of defects in solids (e.g. fibre breakage, matrix cracking and delamination (disbonding of neighbouring plies)). Also, AE can inspect impact damage and study the fracture behaviour of composite materials. In AE, Lam waves are considered as a means of detecting active flaws and assessing damage (and other material attributes) distributed over substantial areas. *Lamb wave* based scanning methods are engaged to distinguish internal damage in multi-layered composites structures.

Vibration based methods (e.g. Coin-tap) are effective for quality control of filament wound carbon fibre reinforced plastic (CFRP) tubes and detection of production defects such as incorrect winding angle or wrong ply orientation.

Radiographic inspection is interesting in industrial applications for isotropic material. For instance, an X-ray photograph can illustrate damage (e.g. cracking, splitting and delamination) in a multi-directional carbon fibre/ epoxy laminate loaded in compression–compression fatigue.

Thermography methods (e.g., lock-in thermography, pulse thermography or vibro-thermography) are useful to detect delaminations, corrosions, surface cracks and voids. Besides, they are relevant to honeycomb constructions and thermoplastic composite welds.

2.1.2. Second conceptual description: Equipment family

The second level of description is the type of study tool: measuring instrument, probe, calibration block, etc. Some tools are only available for a very precise method. This is for example the case of Hammer, which is used exclusively for the resonance method, or the Tube for X-ray method. Here is an example of ultrasonic methods in terms of the parameter family.

- Instrument.
- Search unit.
- Reference.
- Cable.
- Miscellaneous.
- Wedge.
- Encoder.
- Program.

2.1.3. Third conceptual description: Specific techniques

Specific techniques can vary according to the general method. It is clear that the endoscopic technique is specific to a visual test, and can never be found in the thermography method. For example, here are the specific techniques of the Eddy Current Method. However, there are some exceptions, such that the Thickness Measurement exists both in Eddy Currents and in Ultrasonic methods. We can found these following specific techniques:

- Conductivity Measurement.
- Thickness Measurement.
- Eddy Current Array.
- Low Frequency Eddy Current (LFEC).
- High Frequency Eddy Current (HFEC).
- Rototest.

2.1.4. Fourth conceptual description: Dimensional parameters

The dimensional parameters depend on all business parameters and therefore vary according to their respective specificities: the dimensional parameters for an ultrasonic probe are not the same as those of an eddy current probe, also those of an ultrasonic probe are not the same as those of an ultrasonic analysis instrument.

They can also differentiate two equipments used for the same type of control hence identify the most suitable.

For an ultrasonic probe, these parameters are for example:

- Diameter.
- Frequency.
- Length.
- Thickness.
- Depth/Angle.

The conceptual descriptions (e.g. General methods, Equipment family, Specific techniques and Dimensional parameters) cannot only be used for NDT of aircraft structure but also used for other structures, such as in refineries, chemical plants and power plants. For example, the principal industrial uses of magnetic particle inspection are final inspection, receiving inspection, in process inspection and quality control, maintenance and overhaul in the transportation industries (truck, railroad, and aircraft), plant and machinery maintenance, and inspection of large components. However, this research work is conducted to meet the needs of a major Aircraft Company located in our industrial environment, while proposing high added value maintenance expertise for its Customer Support Structure Engineering. In particular, Aircraft components such as aluminum structural parts, titanium engine blades, and metallic composite materials can be readily inspected using eddy current inspection techniques. More generally, NDT inspections have been successful in detecting early cracking and in accelerating corrective actions. Additionally, the integrity of many high performance components in gas turbine engines is critical to aircraft safety. Therefore, management procedures (such as individual engine tracking procedures and realistic inspection and maintenance requirements) must be defined and enforced.

2.2. Information structuring for maintenance equipment's representation

Industrial information systems manipulate and manage large volumes of information that need to be carefully represented and understood in order to generate useful knowledge from the data models. Habitually, Entity–Relationship–Attribute (ERA) modelling or object-oriented modelling (defining class and object hierarchies) are used as data modelling methods [11]. Such methods employ different representation formalisms and codification techniques that are implemented in industrial frameworks for information structuring with a database query processing. However, equipment codifications mean distinct things in different applications, since they do not have to have a shared semantics to be comparable across sources. In addition, when there are many changes in the catalogues of manufacturers, their nomenclatures can become increasingly complex or even opaque in some extreme cases. This happens for example when a supplier has subsequently acquired new companies, purchased stakes in other companies, and made some divestments; or when changing policy on the classification of different manufacturers (e.g. the transition from a technical code to an incremental code). So, a high codification system is fundamental to serve as a means for equipments utilization research in order to improve quality of maintenance equipments use. One component of this is the presentation and comparison of maintenance equipment characteristics with possible substitutions at international and other levels. Statistics show that a vast majority of industrial maintenance equipments can be replaced by elements with the same characteristics. In practical facts, in only a very small number of cases, maintenance teams must mandatory use the same tool described in the development of procedures. Therefore, it is essential to work on a semantic conceptual identification to know the equivalent equipments according with a defined specification. In this context, ontology is an enabling approach that explicitly specifies intended meanings of the conceptualizations (e.g. centralised or distributed categorization) for information sharing and manipulation [12]. Nowadays, ontologies are designed to improve the accuracy of search engines and enable an interoperable communication at the semantic level [13]. The engagement of a coherent ontology is valuable because maintenance support systems' users can reason about the semantic differences or identities among the vocabulary used in several and independently developed databases [14]. In this perspective it is opportune to provide the construction of a hierarchical conceptual structure with a formal support having an underlying logical description. Such that when linked to existing information systems, the hierarchical conceptual structure of domain knowledge can support both a broader overview and some deep analysis. For instance, by investigating on groups of technical equipments with similar functional and behavioural properties, it is possible to find out if there are equivalent alternative equipments that can be used in a target maintenance procedure [15]. The maintainer should be prompted for the location of the alternative equipments with information structuring that provides ways for managing, reappraising, and reusing alternative equivalents for NDT objects. Maintenance equipments are classified according to the main testing/inspection/evaluation use of the main effective characteristics; on the basic principle of only one NDT equipment code for each route of management (i.e. preventive/curative forms with similar characteristics and strength will have the same NDT equipment code).

To identify some common conceptualization of the data, our approach includes the following steps:

- *Analysis of equipments was an essential step*. For the development of our work. Indeed, it is from this analysis and research that key parameters of the equipment, are associated to maintenance equipment's codifications. This consists of referencing the equipments of all programs, and studying the proceedings in which they were called to determine which characteristics were important for the performance of maintenance testing. It appeared that three types of parameters were to remember: three parameters of business on the field use of the tool, three dimensional parameters, and three parameters of effectiveness.
- *The next step was the development of the equipment code from these key parameters*. Initially, we were directed towards a 3-part code (one for each type of parameters), but then it was considered more suitable to use a 2-part code, because the parameters of effectiveness were not really useful in the code. The first part is to say, business settings, is mnemonic, which identifies quickly what tool we have to deal with, while the dimensional part is incremental, because it would be impossible to keep the code short and constant length if it was also mnemonic.

Codifying equipments' identification offers a thought-provoking frame into the intersection of semi structured data with context-dependent semantics (tags and alignments of reference numbers meaning, equipment's online characteristics) and formal reasoning (logical inference, database query processing, or constraint satisfaction method).

The research work presented in this paper is intended to examine whether maintenance experts-as-users can represent domain vocabulary structuring better using conceptual graphs. So, the proposal of conceptual graphs for formal representation of equipments is motivated by communication, information structuring and formal reasoning requirements viewpoints [16,17]. This paper further describes how the suggested approach is appropriate to support formal analysis and to represent graphically knowledge, logic and concepts used in equipment descriptions. The work is done with the intention to render equipment descriptions more user-friendly using conceptual graphs that can improve the readability of the reasoning services in its diagrammatic form. Maintainers-as-users would interpret better the selection of the needed equipment based on procedures' recommendations that is represented formally by knowledge conceptualization principles with associated knowledge reasoning techniques.

3. Graph-based knowledge representation and reasoning

Our choice for knowledge modelling is oriented towards the conceptual graphs formalism [18]. Indeed, on the one hand, it allows the formalization of conceptual and procedural knowledge of a target domain; on the other hand, the provided reasoning tools facilitate the visualization, the enrichment and the verification of the modelled knowledge by end users [19]. Furthermore, there is a formal correspondence between conceptual graphs and Description Logics that is the most implemented language in various knowledge base applications. Also, there are many mappings between conceptual graphs and languages associated to semantic web applications [20,21] (RDF(s) (Resource Description Framework), DAM-OIL (DARPA Agent Markup Language), OWL-DL (Web Ontology Language-Description Logics) or Topic Maps)).

3.1. Conceptual graphs as a formal visual modelling language

The appropriate processing of maintenance knowledge requires the use of a knowledge representation language having a well-defined syntax and a formal semantics. The conceptual graph (CG) formalism [16] can be considered as a compromise representation between a formal language and a graphical language as it is visual and has a range of reasoning processes. Visual languages carry great symbolic meaning in human cultures and range from informal ambiguous sketches to rigorously defined technical diagrams. They have become a key component of human-computer interaction. Conceptual graphs operations provide formal reasoning tools that allow ensuring reliability and enhance the quality of maintenance knowledge-based systems. These are critical factors for their successful use in real-world applications. For instance, these reasoning tools can help the user to determine whether a knowledge-based system does or does not satisfy its purely formal specifications [22].

3.1.1. Basic definitions

A *simple conceptual graph* is a finite, connected, directed, bipartite graph consisting of *concept* nodes (denoted as boxes), which are connected with conceptual *relation* nodes (denoted as circles). In the alternative linear notation, concept nodes are written within []-brackets while conceptual relation nodes are denoted within ()-brackets [23].

A *concept* is composed of a type and a marker [<type>:<marker>], for example [Equipment: Ultrasonic Probe75]. The type of concept represents the occurrence of object class. They are grouped in a hierarchical structure called a concept lattice showing their inheritance relationships. The marker specifies the meaning of a concept by specifying an occurrence of the type of concept. They can be of various natures, in particular: individual, generic (symbol '*' within the marker), quantifiers or sets (the latter by using {}-brackets within the marker).

A conceptual *relation* binds two or more concepts according to the following diagram $[C_1] \leftarrow (\textit{relation's name}) \leftarrow [C_2]$ (means 'C_1 is in relation with C_2'). Each relation has a signature, which fixes its arity (the number of arguments it takes) and gives the maximum types of concept available, to which a relation of the type can relate. In particular, a singular *evolves into* relation captures the notion of transformation over time [24]. The sub-relation definition is sometimes necessary to provide more details in the semantic representation, and then a relation lattice is established.

3.1.2. Formal semantics

Conceptual graphs are provided with semantics in first-order-logic, defined by a mathematical mapping classically denoted by Φ [16]. This shows how the symbols of conceptual graphs theory map into corresponding quantities in logic theory, transforming the axioms of its domain into axioms or theorems of first-order-logic. Concept types are translated into unary predicates and relations into predicates of the same arity. Individual markers become constants. To a vocabulary V is assigned a set of formulas $\Phi(V)$ which translates the partial orders on concept types and relations: if t and t' are concept types, with $t' < t$, one has the formula $\forall x\ (t'(x) \rightarrow t(x))$; similarly, if r and r' are n-ary relations, with $r' < r$, one has the formula $\forall x_1 \ldots x_n\ (r'(x_1 \ldots x_n) \rightarrow r(x_1 \ldots x_n))$.

3.1.3. Reasoning through graph homomorphism

In mathematics, a homomorphism is an abstraction derived from structure-preserving mappings between two mathematical structures [25]. It is a process that combines a set in another, while preserving all the information on the structure of the first set in the second set. Indeed, in many cases, the useful properties of an object will be shared by all objects isomorphic in a bijective map (one-to-one correspondence). In the mathematical field of graph theory a graph homomorphism is a mapping between two graphs that respects their structure [26]. More concretely it maps adjacent vertices to adjacent vertices. A given function from G to H is a graph morphism if the image of every edge of G is an edge of H. If there is a morphism of G into H, we say that classically G "projects" in H (i.e. subgraph matching). In fact, the projection operation is a computational task in which two graphs G and H are given as input, and one must determine whether H contains a subgraph that is a specialization of G. However, its running time is in general exponential, for numerous special classes of graphs (e.g. Trees, Planar graphs, Permutation graphs), the graph isomorphism problem have polynomial-time algorithms, and in practice it can habitually be solved efficiently [27]. It has been showed that the query evaluation and query containment problems of relational structures and databases are equivalent to CG homomorphism problem, in the case of conjunctive, positive and non-recursive queries [23].

3.2. The use of conceptual graphs in NDT

Conceptual graphs are used to express and process maintenance knowledge of text equipment descriptions. The domain vocabulary of the target maintenance domain (procedures of Non-Destructive Testing in aircraft industry applications) is formalized. This vocabulary layer supports the evolution of vocabularies as it can define relations between the different concepts and expresses a community's consensus knowledge about a domain. Graph operations facilitate how to use the reasoning mechanisms in order to facilitate formal descriptions representation of the maintenance procedures. The purpose is to allow the maintenance domain expert (1) to specify the conceptual vocabulary of the domain by using concepts and relationships between these concepts, (2) to specify the axioms and properties of the domain in a graphical way and (3) to make these axioms easily operational in order to perform reasoning with conceptual graph formalism in the context of Non-Destructive Testing in aircraft industry applications.

The interest of creating an explicit conceptual modeling is to guide equipment and method selection for NDT management, since a structured syntax and a fixed domain vocabulary reduce the task of semantic interpretation processing significantly [28]:

- The conceptualization of domain vocabulary with a formal description that would be at an abstraction level potentially independent of changes in manufacturers' catalogues.
- The specification of operational knowledge by using this conceptualization would greatly facilitate the establishment of equivalences between maintenance devices, thereby reducing the delays and costs to organizations and their customers.

We are interested in the following issue: How to provide a formal model to consolidate multiple components correspondences and annotate their description/documentation to allow a rapid decision making in an industrial maintenance centre. Many thesauri are managed jointly on different groups of products. This formal model will be used to uniquely identify any equipments with the NDT method, to index their associated documentation, and to facilitate the semantic search with further explanations.

3.2.1. Ontological domain vocabulary modelling

An ontology model as a clear specification has three roles [29].

- To represent key concepts and relations of the modelling domain in a structural way in order to supply maintenance users clearly understand conceptual domain knowledge.
- To facilitate communication between various domain actors and software tools with a formal semantic conceptualization providing knowledge sharing for problem solving and decision support assistances.
- To serve as a basis for reasoning, since verification (via the projection operation) is essentially based on the father-son rela-

tionships. We have a general question on a standard that indicates the name of a parent, and we want to know if a son, grandson, or great-grandson meets or not the conditions of standard. To do this, just look to see if the tree belongs to the right family. For example, if a standard is for mechanical equipment, electrical equipment will in no way concerned.

The Figs. 2a and 2b are a taxonomic classification showing a very narrow form of ontology, which represents partial domain vocabulary as a set of concepts and relations between them.

3.2.2. Concept characterization in type definition

Defining a type *t* relies on a formal description that specifies the necessary and sufficient conditions for an object being a member of a specific set called type *t*. In practice, it is often sufficient conditions associated to conceptual objects, but does not describe the rules for using these objects and properties satisfied by these objects (other than those that define it). This description is characterized by a simple conceptual graph with a logical specification.

The logical interpretation of a type *t* defined by a description *D* is as follows:

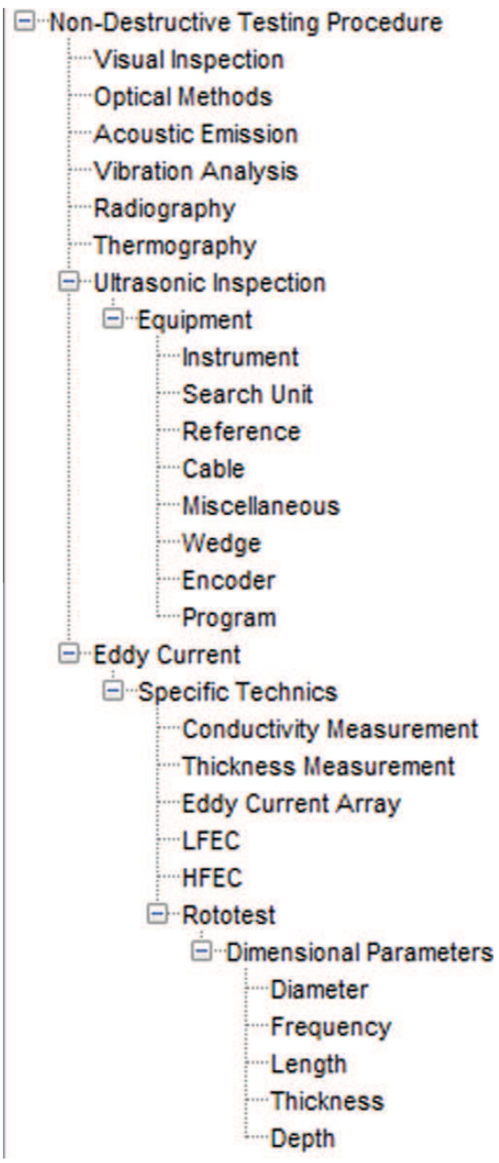

Fig. 2a. Hierarchical structure of domain concepts of NDT in a tree view.

$$\forall x_1 \ldots x_n (t(x_1 \ldots x_n) \leftrightarrow \Phi(D(x_1 \ldots x_n)))$$

In the previous formula, $\Phi(D)$ corresponds to the logical interpretation of the conceptual graph *D* that is the existential closure of the conjunction of all the predicates associated with the vertices (concepts and relations) of the graph [30].

We apply graph-theoretic operations to identify correspondences between type definitions of different concepts of a domain application. Particularly, the CG projection operator makes the comparisons between type definitions represented in conceptual graphs. To identify correspondences between type definitions represented as graphs, the projection achieves a mapping that restrict the labels of the vertices. This operation preserves the graphs' topological structure by finding label substitutions and is semantically equivalent to the logical implication.

Fig. 3 presents the definition of the concept type called "Non-destructive testing (NDT)": NDT is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. The description of the concept type Non-Destructive Testing is logically interpreted by the following formula:

$$\begin{aligned}\forall x : [&Non-Destructive\ Testing(x) \leftrightarrow \exists y, z, t : \\ &(Analysis\ Technique\ (x) \wedge\ Material\ Component\ (y) \\ &\wedge\ Properties\ Evaluation\ (z)\ \wedge\ Damage\ (t)\ \wedge\ Object\ (x, y) \\ &\wedge\ Agent\ (x, z)\ \wedge Without\ (x, t))]\end{aligned}$$

3.2.3. Specification of domain rules and constraints

Using the conceptual graphs framework, it is possible to formally specify domain rules and constraints. There are decidable classes of reasoning with constraints and graph rules, based on projection operation, backward chaining and forward chaining [31]. The specification of specific domain knowledge can be achieved via the use of rules and constraints (obligations and interdictions). A comprehensible set of domain rules and constraints means knowing which NDT procedure is doing what, using what equipment, and according to what work methods. Examples of particular rules and constraints of NDT are described below:

Rule 1: IF is a NDT by ultrasonic method with a Probe tool THEN one can use Crack Detection for faults location and Thickness Measurement for determining porosity/inclusions dimensions and their corresponding fatigue class level.
Rule 2: IF is a NDT by pulsed thermography method THEN a real-time monitoring of certain features (notches under multi-ply composite patching, drilling induced defects on multi-ply laminates, impact damage on carbon fibre reinforced plastic panels) can be obtained using pulsed thermography [2].
Rule 3: The non-destructive examination of external faults are done by the methods of visual inspection or search using a magnifying glass, or other methods such as penetrant liquid or magnetic inspection.
Rule 4: The non-destructive examination of internal defects is mainly carried out with X-rays, γ and ultrasonic waves.
Rule 5: The advantage of Ultrasonic Testing compared to that of the optical methods is the determination of the depth of the defect and the degree of accuracy obtained [32]. For example, the maximum depth of the exfoliation damage is determined by an ultrasonic non-destructive inspection (NDI) [33].
Rule 6: News types of eddy currents probe are able to detect superficial defects less than 60 µm deep metallic joints [34].
Rule 7: Lock-in thermography is a more powerful technique to detect impact damage and transient thermography is more suitable for detecting inclusions [35].

Fig. 2b. Hierarchical structure of domain concepts of NDT in a graph view.

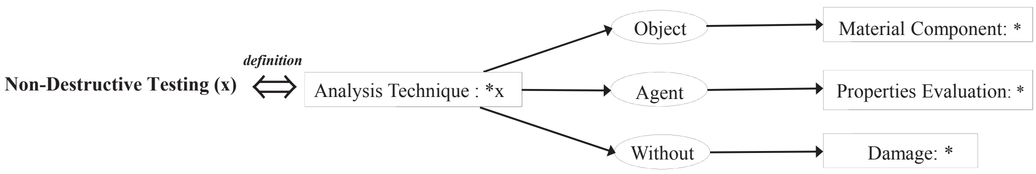

Fig. 3. Definition of the concept type "Non-Destructive Testing".

Rule 8: Spring loaded probes are excellent for situations where constant tip-to-surface angle and pressure is required. These probes are typically used for part sampling and corrosion detection.
Constraint 1: Endoscopic technique is specific to a visual test, and can never be in the thermography method.
Constraint 2: The composite parts of low ductility should not be assessed for thermography.
Constraint 3: Small defects, like cavities or internal microcracks in a metal component, can have serious consequences on the reliability of a mechanical part.
Constraint 4: Each of NDT method possesses it specificities predestining it to some types of procedures associated to mechanical or structural element of the aircraft.
Constraint 5: Relevant information concerning the defects can only be obtained both quickly and precisely, by the selection of several NDT methods having complementary detection capabilities. For example, ultrasonic, Shearography and Infrared thermography methods can be used together to provide active structural health monitoring and to ensure the fast time of control and a good estimation of typical flaws: disbonds, delaminations, wrinkles, porosity, foreign objects and impact damages [32].

The characteristics of the material that may affect NDT method selection are highly dependent on the specific NDT activity under consideration. The Table 1 describes some NDT methods and their important characteristics. Besides, NDT methods having complementary inspection/detection/evaluation capabilities can be used with various kinds of material and in various types of environment for fault/damage monitoring.

The above rules and constraints can be formalized to provide the intelligible analysis that establishes the formal specification of maintenance procedure. More formally, rules and constraints can be represented by some logical predicates that are straightforwardly link to the conceptual graphs with the expressiveness of visual communication to induce creative problem solving [30].

Table 1
NDT methods and their important material characteristics.

NDT method	Characteristic
Liquid penetrant	Flaw must intercept surface
Magnetic particle	Material must be magnetic
Microwave	Material must be electrically conductive or magnetic
Radiography and X-ray computed tomography	Microwave transmission
Neutron radiography	Changes in thickness, density, and/or elemental composition
Neutron radiography	Changes in thickness, density, and/or elemental composition
Optical holography	Surface optical properties

A conceptual rule R ($G_1 \Rightarrow G_2$) is a pair of λ-abstractions ($\lambda x_1,\ldots,x_n G_1$, $k x_1,\ldots,x_n G_2$), where $x_1,\ldots,x_n$, called connection points, enable one to link concept vertices of same label of G_1 and G_2. The logical interpretation of a conceptual rule R ($G_1 \Rightarrow G_2$) is defined as follows: Φ $(R) = \forall x_1 \ldots \forall x_n$ $\Phi(\lambda x_1 \ldots x_n G_1) \Rightarrow \Phi(\lambda x_1 \ldots x_n G_2)$.

The constraints (obligations and interdictions) can be represented by a tuple of the form [36]: <*ConstraintType; ConstraintActivation; ConstraintCondition; ConstraintExpiration; ConstraintTarget*>; where ConstraintType $\in$ {*obligation, interdiction*}; and *ConstraintActivation, ConstraintCondition, ConstraintExpiration*, and *ConstraintTarget* are all well-formed formulas in some logical predicate language.

CGs provide a visual way to describe, specify and interpret the structured knowledge through which constraints proceed; that is, whether they have been activated, violated, fulfilled, or expired [36]. CG based representation enables a user to consider the interactions between rules and constraints, and comprehend them in an insightful and actionable way. CG-based reasoning can be used to check the semantic validity of a knowledge base by confronting it to external expert knowledge (rules and constraints) expressed in terms of conceptual graphs [37].

4. Compliance monitoring for maintenance support services

It is essential to detect and monitor internal and external damages in vital components to receive an early warning for a well-timed maintenance of aircraft structures [38]. The method of technical equipment management has created specific sheets associated to procedures, which define in this way the specific needs of all test procedures. Also, management comprises some specific retrieval information with appropriate functional equivalences of the concerning procedure specifications. For instance, one can collect information about functioning and outcomes of the material resources of the working situation in order to determine means for a protection against overload and short circuit conditions, with recovery actions after removal of the concerning fault condition.

The application example of the proposed approach is a procedure for the management of specific maintenance procedures. These procedures are for preventive and corrective maintenance actions who require equipments dedicated to Non-Destructive Testing in aircraft industry applications. Aircraft components are habitually maintained to preserve them operational, reliable and to minimize failures. Parts only submitted to corrective maintenance are warranted when failure costs are reasonable and when safety constraints are supple. In conventional aircraft inspections, Non-Destructive Testing (NDT) techniques for detecting complicated damage (e.g., from matrix cracks, delaminations and disbondings) are therefore essential to ensure the safety of the structural components. Examples includes left barrel showing crack after subjected to dye penetrant test [39] or an acoustic inspection system revealing some damages from nearly invisible defects and provide information on its nature and size [40].

4.1. Building conceptual graphs of Non-Destructive Testing

The department of Customer Support maintenance Engineering participates in the development of maintenance methods and procedures. For instance, using the methods of Non-Destructive Testing, such as ultrasound, X-ray or eddy currents, it is possible to answer questions associated to the maintenance of aircraft industry structures. All these tests require a large number of instruments and tools developed by various companies, including suppliers and subcontractors are only examples. In addition, a target company also has its own departments for the development of tools.

The problem is that all these companies have their own naming policy and referencing facilities for their catalogues, which makes difficult for airlines, looking for a tool to meet specific criteria. Moreover, these catalogues are subject to significant and numerous changes, both internally to each manufacturer (organizational, conceptual or technological changes), but also because of acquisitions or mergers. The formal visual reasoning is a useful tool for facilitating effective and efficient sharing of information in NDT-based maintenance management. The practical reasoning elements monitor adequacy of the procedures to ensure that such procedures invoke good maintenance practices and airworthiness requirements. Compliance monitoring can include a feedback sys-

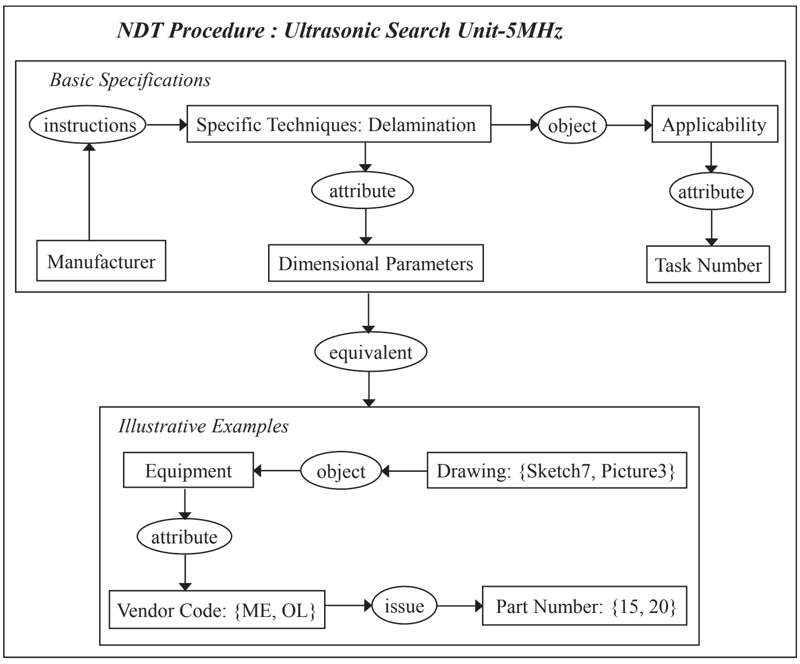

Fig. 4. Partial modelling of a technical procedure in conceptual graph.

tem to suggest needed corrective actions ensuring that the aircraft is in a condition for safe operation.

For the construction of a conceptual graph, we need a formal and detailed collection of nodes, relations and questions. The nodes can be contexts, maintenance plans or events. There are specific relations for each type of node and nested conceptual graphs enable association of any concept node with a partial internal description. This is done with the Conceptual Graphs Graphical User Interface (CoGUI) encompassing both conceptual graphs applications and conceptual graphs editor [41]. An example of conceptual graph modelling for the technical procedure (specification statement plus equivalent equipment) is presented in Fig. 4.

4.2. Graph-based compliance monitoring in NDT procedures

The semantic verification of a compliance checking between equipments and technical procedures consists in checking that the equipment specifications respects a set of specifications described in a maintenance procedure. This verification is done by means of the reasoning operations of conceptual graphs (specifically projection operation). The mechanism of semantic verification of a conceptual graph consists of checking that there exists a projection from any positive constraint (obligation) and that of a projection from any negative constraint (interdiction) does not exist in this conceptual graph [30]. Thus, it becomes easy to visually show to the user where the anomalies occur with the identification of the constraints that are not satisfied in terms of conceptual graphs, very similar to the way equipment descriptions are modelled. That, in turn, simplifies application of our approach, as the maintenance expert does not have to take care of the technical details of complex logic formula. Also, it is possible to study the refinement restoring the coherence and completeness of a conceptual graph knowledge base, which is not semantically valid with respect to constraints [37].

The problem of equivalence between equipments can be reduced to a problem of semantic specialization of graphs (via the projection operation of conceptual graphs). Each technical procedure P requires equipment E whose characteristics are specified by a graph. So E can be a tool used for a procedure P, if and only if the graph of E can be projected on the graph of the reference Equipment R specified in the procedure P. Thus each equipment or procedure has a graph type definition will be the basis of the reasoning for the equipment management.

In the context of our verification approach illustrated in Fig. 5, the reasoning mechanism implemented is mainly based on a comparison of conceptual graphs with the mechanism of projection. Indeed, the projection is a technique to check whether a given graph is more specific than another, by specialization of the general concepts and relations towards more specific concepts and relations. In other terms, one class X maps M another class Y if, each property of X corresponds to one of Y even [42]. According to some views, two isomorphic objects can be regarded as equivalent, or at least substitutable with common features related to the subset of their

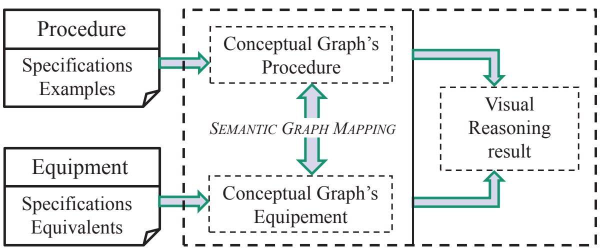

Fig. 5. A graph-based method for NDT compliance verification.

shared properties. A graph matching is applied in the area of NDT management to find similarities between NDT equipments from their functional properties. The existence of such mapping between equipments shows a relationship between their functional properties for NDT operations.

Cognitive values of CGs are that they stimulate heuristic creativity through visual reasoning easing the understanding by the direct stakeholders. Thus, this method lays more emphasis on the visualization of the elegant steps of reasoning by avoiding the difficulty of handling the logical formulas that is often found in methods for automatic verification of models ("model checking"). To achieve optimal NDT inspection performance, there are several important parameters to consider when choosing effective maintenance equipment. Thus, in addition the appropriate data sheets structure for equipment management can be linked to technical data sheets for procedures that define the corresponding specifications actually required for an equipment to perform a considered NDT inspection. It is necessary to adopt common technical requirements and explicit maintenance procedures to ensure the continuing airworthiness of aircraft and aeronautical products.

4.2.1. Case 1: verification with an unfavourable result

One maintainer named LAK projects/wants to do a procedure Ref. A with an equipment Ref. B. LAK wants to know if this equipment meets the specified requirements in the target procedure.

Query: Is it possible to achieve the procedure A with the available equipment B?

Argumentation: The procedure Ref. A, is an eddy current test procedure for detecting superficial cracks less than 2 mm deep in different orientations. Whereas, the equipment B is associated to X-Radiography, there is currently no X-Radiography procedure that would meet the requirements to properly detect cracks. Concretely, in conceptual graph-theoretic terms, there is no projection from the graphical specification of equipment Ref. B to the graphical specification of requirements described in procedure Ref. A.

Answer: In conclusion, the application of equipment Ref. B to the inspection of these superficial cracks is rather limited and it is not an alternative to perform the procedure Ref. A.

4.2.2. Case 2: verification with a favourable result

Let us consider an eddy current procedure Ref. C for an area (e.g. wing) of the aircraft industry that is simple to access. In general, such a NDT inspection is made using a "straight high frequency probe". Now, suppose for whatever reasons, this equipment is not obtainable; however, a bent probe Ref. D is available.

Query: Is it possible to achieve the procedure C with the equipment D?

Argumentation: Probes used to perform eddy current inspections can vary to better suit specific applications. The bent probe capability is superior to the straight probe capability in its ability to achieve optimal inspection performance because it provides more favourable key factors (inspection coverage, sensitivity and frequency). Hence, in conceptual graph-theoretic terms, it is possible to select the correct bent probe characteristics for a successful satisfaction of graph constraints specifying requirements described in procedure Ref. C.

Answer: Classically, such a probe is intended for the use of specific cases in not easily accessible areas (complex shapes). However, their unusual shape does not make them incompatible with other areas of the target system, easily accessible. As a result, the remarkable advantages of bent probe allow improved inspection capabilities and significant time savings.

5. Conclusion

In this document, we presented a formal approach of mechanisms to check whether technical equipments are compliant with technical procedures. The central part of the paper is about the translation of basic CGs research findings for describing both the semantics of specifications and the semantics of compliance checking reasoning. The application of CGs operations contributes to the understanding of how information can be used for information retrieval and problem-solving for equipments management in NDT. Equivalent alternatives play an important role in accessible maintenance practices since certain types of equipments may not be accessible to all maintainers. The proposed approach assists maintainers in providing and managing appropriate equivalent alternatives. Further analysis of procedure specifications allow to improve the identification of the needed equipment in order to facilitate the management of all the equipments. In addition, it is possible to establish a system of functional equivalences, to have a better visibility of equipment characteristics, and also propose a range of equipments which are applicable in maintenance purposes.

In the conceptual graph formalism that is used as modelling language, the reasoning is essentially based on the projection operation to conduct compliance audits in relation to target specifications. This projection can be interpreted as a calculation of the graph search as specific as between a pair of conceptual graphs. The goal is to improve understanding of the verification steps with more explicit language which by its nature allows for better visual clarity of reasoning. Thus, we thought it advantageous to be able to deduct the compliance or non-compliance with a standard based on specific parts belonging to the conceptual graphs modelling the specifications of technical procedures. Furthermore, it is a process of formal proof, because the graph formalism has a rigorous foundation, especially through equivalence with logic languages. This ensures a good quality of knowledge modelling, while ensuring compliance with the specified requirements.

Only the "maintenance support" is impacted by improvements related to the identification of equivalent equipment in NDT maintenance services through the introduction of new ways of structuring and encoding NDT operations with their required equipment features. The ontology-based knowledge representation and reasoning improves the maintenance logistics, with a better traceability of the search for information in maintenance support. So, the associated Information Technology system will provide an inventory control improvement that influences maintenance task planning and aircraft availability. Also, consolidating the fundamental technical strengths and supporting web collaborative solutions are required to improve the level of knowledge based engineering support for aircraft component maintenance [43]. Likewise, there is the necessity for improved methodological support and adherence, with a better transparency and traceability of knowledge to carry out and/or control a continued airworthiness NDT of aircraft structures and/or components [44].

Acknowledgments

The author is indebted to Nwana Albert Nwanlengseh, Malik Yahiaoui and Adrien Zeanh for their helpful comments and suggestions. Special thanks are due to Pr. Blaise Nsom Eyenga Ndille for his lucid and insightful advices. Finally, thanks go to three critical reviewers their thoughtful evaluation and precious feedback.

References

[1] N.S. Rossini, M. Dassisti, K.Y. Benyounis, A.G. Olabi, Methods of measuring residual stresses in components, Materials & Design 35 (2012) 572–588.
[2] N.P. Avdelidis, D.P. Almond, A. Dobbinson, B.C. Hawtin, C. Ibarra-Castanedo, X. Maldague, Aircraft composites assessment by means of transient thermal NDT, Progress in Aerospace Sciences 40 (2004) 143–162.
[3] A. Mahoon, The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures, Composites 3 (1988) 229–235.
[4] K. Diamanti, C. Soutis, Structural health monitoring techniques for aircraft composite structures, Progress in Aerospace Sciences 46 (2010) 342–352.
[5] S.K. Bhaumik, M. Sujata, M.A. Venkataswamy, Fatigue failure of aircraft components, Engineering Failure Analysis 15 (2008) 675–694.
[6] T. Mickens, M. Schulz, M. Sundaresan, A. Ghoshal, A.S. Naser, R. Reichmeider, Structural health monitoring of AN aircraft joint, Mechanical Systems and Signal Processing 17 (2003) 285–303.
[7] P. Moreu De Leon, V. González-Prida Díaz, L. Barberá Martínez, A. Crespo Márquez, A practical method for the maintainability assessment in industrial devices using indicators and specific attributes, Reliability Engineering & System Safety 100 (2012) 84–92.
[8] S. Yashiro, J. Takatsubo, N. Toyama, An NDT technique for composite structures using visualized Lamb-wave propagation, Composites Science and Technology 67 (2007) 3202–3208.
[9] D.S. Forsyth, M. Genest, J. Shaver, T.B. Mills, Evaluation of nondestructive testing methods for the detection of fretting damage, International Journal of Fatigue 29 (2007) 810–821.
[10] Q. Jiang, C.-H. Chen, L.P. Khoo, Analytical algorithm of inductive field for realizing a smart Eddy current NDT system, Engineering Computations: International Journal for Computer-Aided Engineering and Software 20 (2003) 835–854.
[11] B. Nuseibeh, S. Easterbrook, Requirements Engineering, third ed., Encyclopedia of Physical Science and Technology, Elsevier Science Ltd., 2003.
[12] T.R. Gruber, A translation approach to portable ontology specifications, Knowledge Acquisition 5 (1993) 199–220.
[13] T.R. Gruber, Ontology of Folksonomy: a mash-up of apples and oranges, International Journal on Semantic Web and Information Systems 3 (2007) 1–11.
[14] Y. Ducq, D. Chen, B. Vallespir, Interoperability in enterprise modelling: requirements and roadmap, Advanced Engineering Informatics 18 (2004) 193–203.
[15] Z. Cheng, X. Jia, P. Gao, S. Wu, J. Wang, A framework for intelligent reliability centered maintenance analysis, Reliability Engineering & System Safety 93 (2008) 806–814.
[16] J.F. Sowa, Conceptual Structures: Information Processing in Mind and Machine, Addison-Wesley, New York, USA, 1984.
[17] J.F. Sowa, J.A. Zachman, Extending and formalising the framework for information systems architecture, IBM Systems Journal 31 (1992) 590–616.
[18] J.F. Sowa, Knowledge Representation: Logical, Philosophical, and Computational Foundations, Brooks Cole Publishing Co., Pacific Grove, CA, 2000.
[19] M. Chein, M. Croitoru, M.-L. Mugnier, Visual reasoning with graph-based mechanisms: the good the better the best, The Knowledge Engineering Review 28 (2013) 28–51.
[20] H. Yao, L. Etzkorn, Automated conversion between different knowledge representation formats, Knowledge-Based Systems 19 (2006) (2006) 404–412.
[21] O. Carloni, M. Leclère, M.-L. Mugnier, Introducing reasoning into an industrial knowledge management tool, Applied Intelligence 31 (2009) 211–224.
[22] B. Kamsu-Foguem, V. Chapurlat, Requirements modelling and formal analysis using graph operations, International Journal of Production Research 17 (2006) 3451–3470.
[23] M. Chein, M.-L. Mugnier, Graph-based Knowledge Representation: Computational Foundations of Conceptual Graphs, Advanced Information and Knowledge Processing, Springer, London, United Kingdom, 445p (Hardcover, ISBN 978-1-84800-285-2, 01.10.08).
[24] R. Thomopoulos, J.R. Bourguet, B. Cuq, A. Ndiaye, Answering queries that may have results in the future: a case study in food science, Knowledge-Based Systems 23 (2010) 491–495.
[25] N. Jacobson, Basic Algebra, 2 (second ed.), 2009, Dover (ISBN 978-0-486-47187-7).
[26] P. Hell, J. Nesetril, Graphs and Homomorphisms, Oxford Lecture Series in Mathematics and Its Applications, Oxford University Press, 2004 (ISBN 0-19-852817-5).
[27] V. Arvind, J. Torán, Isomorphism testing: perspectives and open problems, Bulletin of the European Association for Theoretical Computer Science 86 (2005) 66–84.
[28] A. Saxena, B. Wu, G. Vachtsevanos, A hybrid reasoning architecture for fleet vehicle maintenance, IEEE Instrumentation and Measurement Magazine 9 (2006) 29–36.
[29] B. Kamsu Foguem, T. Coudert, C. Béler, L. Geneste, Knowledge formalization in experience feedback processes: an ontology-based approach, Computers in Industry 59 (2008) 694–710.
[30] J.-F. Baget, M.-L. Mugnier, Extensions of simple conceptual graphs: the complexity of rules and constraints, Journal of Artificial Intelligence Research 16 (2002) 425–465.
[31] J.-F. Baget, M. Leclère, M.-L. Mugnier, E. Salvat, On rules with existential variables: walking the decidability line, Artificial Intelligence 175 (2011) 1620–1654.

[32] C. Garnier, M.-L. Pastor, F. Eyma, B. Lorrain, The detection of aeronautical defects in situ on composite structures using Non Destructive Testing, Composite structures 93 (2011) 1328–1336.
[33] M. Liao, G. Renaud, N.C. Bellinger, Fatigue modeling for aircraft structures containing natural exfoliation corrosion, International Journal of Fatigue 29 (2007) 677–686.
[34] L.S. Rosado, T.G. Santos, M. Piedade, P.M. Ramos, P. Vilaça, Advanced technique for non-destructive testing of friction stir welding of metals, Measurement 43 (2010) 1021–1030.
[35] D. Bates, G. Smith, D. Lu, J. Hewitt, Rapid thermal non-destructive testing of aircraft components, Composites Part B: Engineering 31 (3) (2000) 175–185.
[36] M. Croitoru, N. Oren, S. Miles, M. Luck, Graphical norms via conceptual graphs, Knowledge-Based Systems 29 (2012) 31–43.
[37] J. Dibie-Barthélemy, O. Haemmerlé, E. Salvat, A semantic validation of conceptual graphs, Knowledge-Based Systems 19 (2006) 498–510.
[38] U. Polimeno, M. Meo, Detecting barely visible impact damage detection on aircraft composites structures, Composite Structures 91 (2009) 398–402.
[39] R. Sharma, M. Srinivas, Failure analysis of left barrel of an aircraft engine, Engineering Failure Analysis 16 (2009) 1468–1473.
[40] L.P. Dickinson, N.H. Fletcher, Acoustic detection of invisible damage in aircraft composite panels, Applied Acoustics 70 (2009) 110–119.
[41] GraphIK Team, CoGUI, Conceptual Graphs Graphical User Interface, User Guide. <http://www2.lirmm.fr/cogui/index.php> (last accessed 02.06.12).
[42] A. Etien, C. Rolland, Measuring the fitness relationship, Requirements Engineering Journal 10 (2005) 184–197.
[43] G. La Rocca, Knowledge based engineering: between AI and CAD, review of a language based technology to support engineering design, Advanced Engineering Informatics 26 (2012) 159–179.
[44] W.J.C. Verhagen, P. Bermell-Garcia, R.E.C. van Dijk, R. Curran, A critical review of knowledge-based engineering: an identification of research challenges, Advanced Engineering Informatics 26 (2012) 5–15.

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