Linking Hierarchical Task Analysis to good practices

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ABSTRACT

Hierarchical Task Analysis is one of the better-known tools for Ergonomics / Human Factors: here it is employed as a step between data collection and the production of Good Practice for industry. The specific example used in this paper is non-destructive inspection in aviation. For the continued airworthiness of civil aircraft, regular inspections are required to ensure that defects do not develop to potentially dangerous levels. These inspections use a variety of technologies all of which require both the human and the technology to function reliably. In this study seven inspection technologies were analysed using this methodology to produce good practices usable directly by the aviation industry. One specific technology is used as an exemplar. Each good practice derives from a consideration of the success/failure of a specific step in the task. In addition to providing the good practices, this work includes details on why these practices are indeed good as a further aid to usability. Finally, the good practices formed the basis for audit checklists for self-checking of implementations of the technologies.

KEYWORDS

Good Practices, audits, aviation inspection

Introduction

This paper concerns a methodological issue that begins in a quite straightforward manner in our field of ergonomics / human factors (EHF): the use of hierarchical task analysis (HTA). However, it proceeds to be used as a step to develop good practices usable by industry. The specific domain is that of inspection and maintenance of civil aircraft, particularly what is known as Non-Destructive Inspection or NDI. The work arose from the in-service failure of a jet engine component, a titanium hub, that caused fatalities in 1998 at Pensacola, FL, and was found by the National Transportation Security Board (NTSB, 1998) to have inspection failure as a causal factor. As a result, the author was asked by the Federal Aviation Administration (FAA) to follow up the NTSB report with a study that would develop best practices for the NDI technique used, specifically Fluorescent Penetrant Inspection, known by yet another acronym: FPI. The subsequent report (Drury and Watson, 1999) was a result of the author and a team of NDI specialists from the FAA visiting FPI operations at several sites to analyse the tasks involved and apply information and models from human factors to derive best practices that could be applied throughout the industry. This report was subsequently used by several operators to help improve their own FPI operations. In the current paper, the steps required to turn observations and literature into good practices via HTA are developed for FPI. Although this specific technique is widely used in non-destructive inspection, there appears to be no reason that these steps are not more widely applicable to other jobs and tasks beyond inspection and beyond civil aviation.

The NDI literature pertinent to aviation safety focuses on Inspection Reliability, i.e. the probability of detecting a defect of a specific size by the inspector using the technique, because defect size directly affects residual strength of a component. Typically, this is expressed as a graph relating probability of detection (PoD) to defect size to produce a "PoD curve". The PoD curve requires both technology and a human inspector, so that any analysis must cover both aspects and their interaction. In fact, the PoD curve is an explicit part of the way in which overall aircraft safety is assured by manufacturers and regulatory authorities: the MSG-3 process, named after the Maintenance Safety Group (https://www.skybrary.aero/index.php/Maintenance_Steering_Group-3_(MSG-3). This process searches for all failure modes of an aircraft and seeks to ensure that no single failure can result in an accident. One way to help ensure this level of safety is to perform scheduled inspections to detect cracks, corrosion, loose parts etc., which obviously requires a specific PoD curve to determine when to inspect before a defect grows to a size that threatens safety.

Each part of the methodology used here (literature, observation, HTA, logical errors, best practices) is well known in EHF practice (e.g. Wilson and Sharples, 2015; Shepherd, 1998), but the direct transition to best practices that address each element has received less attention. Note that the title was changed from Best Practices to Good Practices in recognition of the inevitability that not all the best practices were discovered, and that what is "best" will naturally change as the technology and our understanding improve.

Methodology Development

One starting point for this study was the extensive analysis of the FPI task that was implicated in the jet engine blade hub failure reported in NTSB (1998). The other was a listing of the most-used NDI technologies in aviation airworthiness inspection. The analysis by McIntire and Moore (1993) of the frequency of airworthiness directives issued by regulatory authorities, both for all U.S. Aviation and for large transport aircraft was useful here. The specific techniques that comprise over 90% of the Airworthiness Directives analysed are:

Visual Inspection	Borescope Inspection
Radiographic Inspection	Fluorescent Penetrant Inspection
Magnetic Partial Inspection	Eddy Current Inspection
Ultrasonic Inspection	

The original FPI analysis was a part of this list and so provided the format of the methodology for the other tasks.

In this study, the inspection task was observed and inspectors interviewed while working, to determine exactly how the whole job was performed and what they considered to be best practices. Finally, these sources of data were consolidated into an HTA using whatever level of depth was required to cover all of the observations and prior technical knowledge. At this stage, the HTA was really just a Hierarchical Task Description, as no analysis had yet been performed (e.g. Annett, 2008, p69). From the elements of the task description, the correct outcomes could be listed. At this point, analysis could begin by comparing the demands of each task element with known capabilities and limitations of both the inspector (see prior literature, e.g. See, 2012) and the technology (e.g. Tracy, 1999; NTIAC, 1997), so that the errors or variances at each step could be deduced and eventually controlled. This use of a specific literature (inspection reliability) rather than a more general technique for deriving errors (e.g. SHERPA, Embrey; 1986) was done partly so that users of the reports (inspectors, managers) would see directly relevant references, and partly to capitalize on the accumulated detailed knowledge of inspection, (e.g. Drury, Prabhu and Gramopadhye, 1990).

Is becomes obvious when many HTAs are performed on different but related activities, that some of the tasks and sub-tasks are repeated throughout the set. That was certainly true for the NDI techniques studied here. To prevent unnecessary repetition, an earlier generic task description of inspection (Drury et al., 1990; Drury and Watson, 2002) was used to derive generic good practices applicable across most techniques of NDI. These good practices were derived from the EHF literature applicable to inspection (e.g. Drury, 2019), covering topics such as speed vs. accuracy, training/selection, lighting, human/computer interaction and interpersonal system design. In this way, a simple table for each technique could be used to show the applicability of the generic good practices in that instance, as shown later as an example.

The other common factor to many of the technologies is that they rely on the human inspector searching a more-or-less veridical display to locate potential defects. This is almost identical to visual inspection which can be, for example, of a fuselage joint, compared with inspection of an X-ray image of the same component. What the image shows in the two cases may be quite different, but the human issues are very similar. Thus, the relatively low technology inspection technique of visual inspection becomes a key similarity between the various NDI manifestations. Hence, Visual Inspection was the first to be studied in this work, although that is not reported in detail here.

The plan of the overall study was then to use the methodology developed earlier for FPI, then to extract generic good practices, next to study visual inspection, and finally to complete the other techniques from the same perspective. As noted earlier, the sources of information were the NDI literature, specific documents at sites visited, observation and discussion with job incumbents at each site, and earlier information collected by the author and colleagues concerning NDI jobs, e.g. Drury et al. (1990).

Results

For the generic good practices, the list of generic functions of inspection was the starting point. Each of the major generic functions (Initiate, Access, Search, Decision, Response) will logically have specific correct outcomes and logical errors. For example, errors in the Search function, whose correct outcome is “Indications of all possible non-conformities detected and located” can be derived as:

Indication missed	False indication detected
Indication mis-located	Indication forgotten before decision on its severity

These can then provide guidance from literature and observation to derive good practices that can reduce the probabilities of these errors. In this paper, we will not use visual inspection as our example, but focus on the originally-studied task of Fluorescent Penetrant inspection (FPI).

In the NDI Capabilities Handbook (NTIAC 1997, p7-3), a typical source referenced by the NDI community, the task is set out as clean the object, apply a penetrant fluid for long enough to ensure penetration into any cracks, remove the excess penetrant, apply a developer to improve visual contrast between the surface and any cracks, and finally visually inspect the object. After observation of several types of object being inspected at different sites with different processes, the top-level HTA in Figure 1 was constructed. The Plan, not shown in Figure 1, was to perform tasks in order. Note that the final top-level task (7.0) is exactly the list of generic inspection functions given earlier. The essence of FPI is to increase the target/background contrast (of cracks) by coating the object in a fluid with low surface tension that fluoresces under the ultra-violet illumination provided for the actual inspection in 7.0 Read Part for Defects.

Using this as the organizing level of the HTA, each task had to be expanded through re-description (Annett, 2008, p70) to get closer to the level at which specific good practices could be formulated, based on the outcomes and errors of that task. Figure 2 shows the re-described sub-tasks for one task, 3.0 Apply Penetrant. At this level, tasks are not necessarily sequential, so that the Plans are included. Thus, there are three ways of penetrant application, only one of which is used in any particular application.

So far, this is all standard practice in HTA (Shepherd, 1998) but the specific goal of the study was to translate the findings into good practices usable by engineers, managers and inspectors in industry. This involved taking each sub-task, asking how it could succeed or fail based on knowledge of the characteristics of the inspector and the technology, using a table like Table 1 for visual inspection. Observation of the actual practices used, and searching records for instances of failure, pointed to many of both good practices used and dubious practices used.

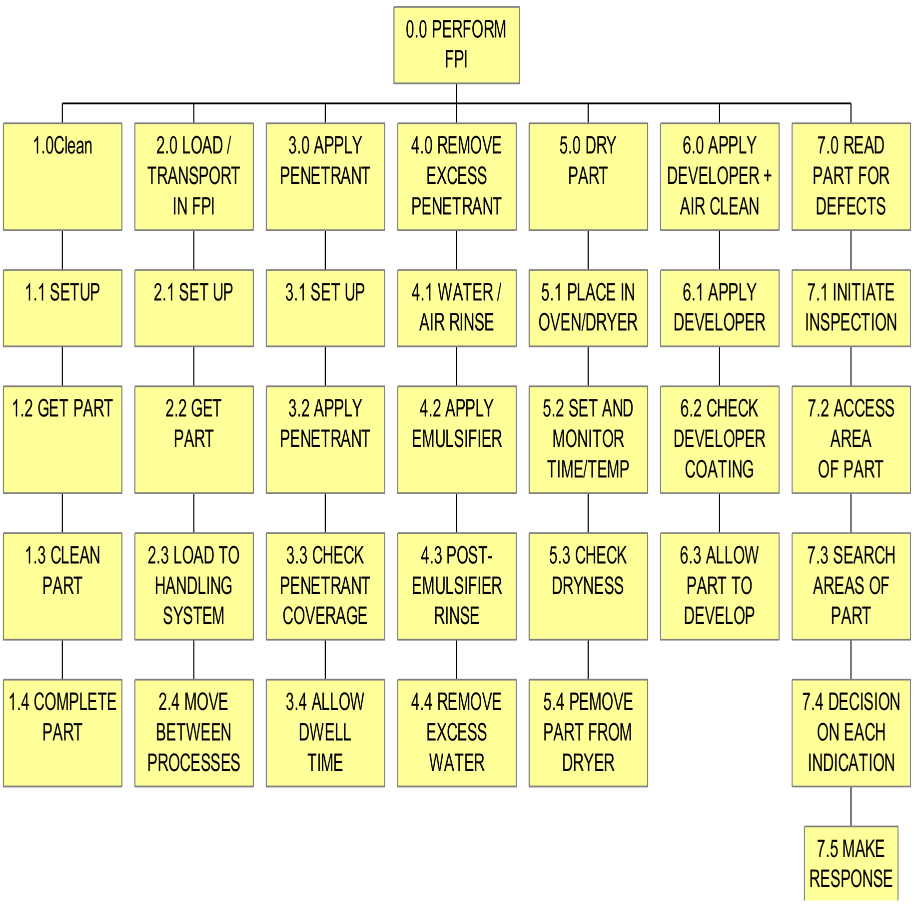

Figure 1. Top-level HTA for Fluorescent Penetrant Inspection.

The dubious practices could then be inverted to suggest good practices not currently in use. For example, contrary to the standard visual inspection tasks, the visual inspection task embedded in FPI (7.0, Read Part for Defects) uses ultra-violet light. This requires a darkened inspection booth for dark adaptation of the inspectors' eyes. Dark adaptation is addressed in current practice by requiring the inspector to wait 2 minutes in the darkened booth before inspecting any objects. However, in practice inspectors either wildly underestimated the time of 2 minutes as they were eager to start the task, or they stated that as experienced inspectors they did not need this dark adaptation time. There are various EHF objections to these current practices. First, dark adaptation is well-known to be a continuous process rather than a sudden event (e.g. Howarth, 2015 p 682, quoting research from 1937). Thus the 2 minutes allowed by current practice is arbitrary and indeed rather short: 10-20 minutes would allow more complete adaptation, but would hardly be practicable for the FPI task. Second, training and experience of inspectors is not an issue for the bio-chemical functioning of the retina. Third, many inspection booths contained sheets of paper which fluoresced in ultra-violet light preventing dark adaptation from proceeding. Also, many inspectors wore clothing such as shirts or lab coats that also fluoresced under the lighting in the booth, again partially negating dark adaptation. These observed errors can be logically negated to produce good practices, e.g. avoid light clothing.

The list of good practices for FPI has too many entries to include here. Thus, Table 1 shows just the first few items from 3.0 Apply Penetrant. Some of the good practices have more than one component, for example the third entry in the table. Note that the table includes a column for "Why" explaining the reasons for the good practice to users who are not necessarily familiar with EHF. Indeed, many organizations and users regard ergonomics as dealing with musculoskeletal injuries and human factors as reasons for poor human behaviour, e.g. the "Dirty Dozen" of Gordon Dupont (Dupont, 1998). Using a "Why" column for each of the 87 good practices generated 146 entries, mainly to help non-EHF users to understand their processes in EHF terms, and hopefully be able to apply these EHF explanations in other parts of their work. Across the whole set of seven NDI techniques, there were a total of 455 good practices specific to each technique although of course there are many good practices common to two or more techniques, e.g. improved documentation practices.

For each of the good practices, a checklist item was included in an Audit format so that users could check on whether their system and operating procedures met these good practices.

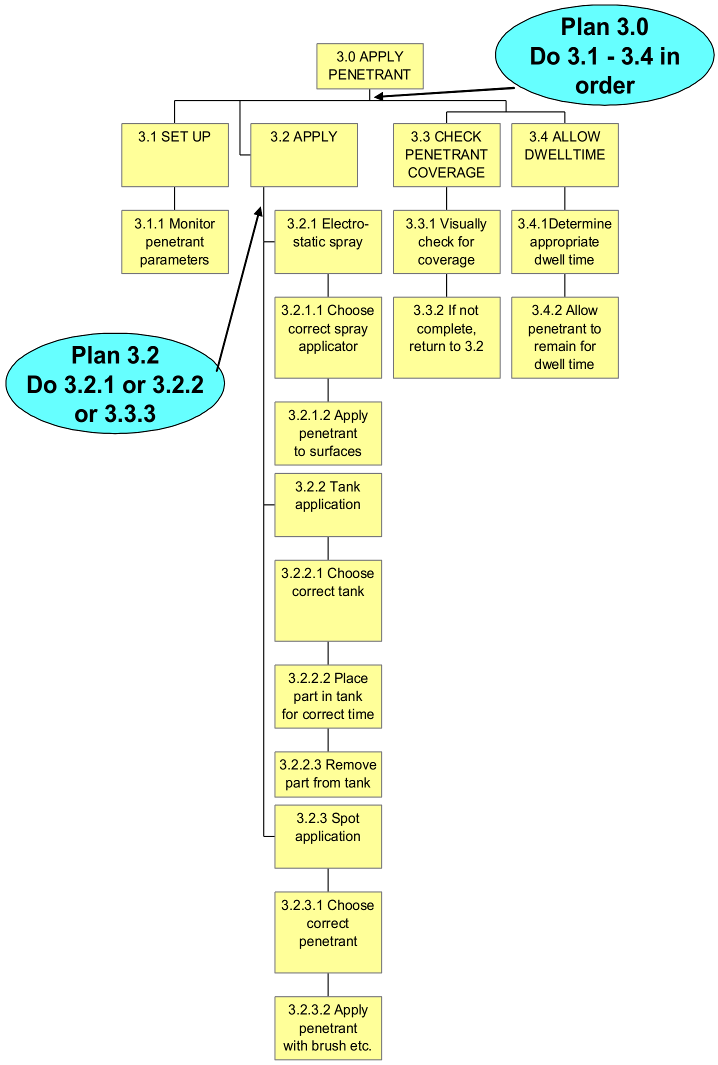

Figure 2. Detailed re-description of 3.0 Apply Penetrant.

Table 2 shows part of this checklist for 3.0. Apply Penetrant. As with the "Why" column, these Audit Checklists are designed to help show potentially naïve users of EHF how aspects of our discipline can apply in practice. The explanations of what are good practices and why does not end with these tables: A detailed narrative with citations to publications is provided for each technique so that users with interest beyond following of good practices have a suitable place to begin their research on each topic.

Discussion

Although EHF aspects of NDI inspection do appear in the EHF literature from time to time (e.g. Arbab and Nathan-Roberts, 2018), a comprehensive analysis to benefit users has been lacking. This paper has used a relatively straightforward application of the techniques of Hierarchical Task Analysis as the organizing principle to relate task steps not just to find the usual human/system mismatches, but to provide users naïve to EHF with tools to improve particular jobs. The first product, for FPI (Drury and Watson, 1999), was utilized by the original airline involved in the NTSB investigation referenced earlier. The second, on visual inspection (Drury and Watson, 2002) has been read over 6000 times on ResearchGate (the author's most "read" publication), although their definition of "Read" may not indicate a complete reading.

Table 1. Examples of good practices for one sub-task of FPI: 3.2.1. Apply Penetrant (spray)

Process	Good Practice	Why
Apply penetrant (spray)	Train operators to move spray gun and component so that all areas can be reached.	1. Incomplete coverage can cause cracks to be missed where no penetrant was applied.
Apply penetrant (spray)	Make the spray gun easier to manoeuvre by suspending or balancing the weight of the hose. Also choose the lightest and most flexible hose.	1. A more manageable spray gun helps the operator reach all areas of the component, preventing missed cracks where no penetrant was applied. 2. Choosing a light and flexible hose, and balancing its weight makes the gun move manoeuvrable.
Apply Penetrant (spray)	Design the drum-to-spray gun connections so that each spray gun can only be connected to the correct drum. Example: Different sized fittings, reversal of male and female coupling on lines.	1. Applying the wrong penetrant can reduce crack visibility, particularly for small cracks. 2. Physically-different fittings reduce the probability of a wrong connection to zero.
Apply penetrant (tank)	Design process indicator dials (e.g. temperature, water pressure) to be easily readable. Place them at eye height with appropriate lighting.	1. Indicators are only useful if they are easy to see and interpret. Errors will go unnoticed if dials are at knee height, or are difficult to interpret and record.
Apply penetrant (tank)	Label all process tanks and booths with clear, understandable and visible labels. Example: "Pre-wash solvent" as well as "Turco4181-L"	1. Errors in moving components to the wrong tank are rare, but can reduce cleaning effectiveness and cause cross-contamination of tanks. 2. If tanks have understandable as well as technical labels, errors are less likely and

		training is more rapid.
Apply penetrant (spot)	Ensure that the containers for the two penetrant systems are clearly differentiable. Example: Different coloured cans, can placement on opposite sides of booth, clear and understandable labels on can.	1. Error of using the wrong can may reduce visibility of cracks, particularly small cracks. 2. The more ways in which the can is different, the more redundancy is available to prevent this error. Small, technical labels (e.g. SPOP084) are not sufficient to eliminate this error.

The seven NDI techniques listed earlier were analysed in turn to provide a comprehensive reference. This source (Drury, 2002) is titled *Handbook of System Reliability in Airframe and Engine Inspection*, and was available on the FAA website (www.faa.gov) for a number of years. At present it is no longer listed and so has been made available at http://ergonomicsgroup.com/. There have been no compilations of numbers of reads or downloads of this Handbook.

Although HTA has been used here as a way to organize and derive a logical list of good practices, there is no guarantee that alternative methods would not have produced equivalent results. However, HTA has some unique characteristics that were useful here, and are probably useful in other domains where good practices need to be derived:

1. HTA has provided a framework that explicitly integrates the current, rather extensive, technical knowledge of EHF in inspection with the technical knowledge of NDI in a literature that often ignores human consideration.
2. The organizing framework of HTA has proven to useful for users of the good practices as it related each good practice specifically to the part of the task where it will be applicable. Users, e.g. in training seminars, have appreciated this direct link between specific tasks they perform and the good practices related to that task.
3. HTA provides a logical and practical way to break a task into its components. Successive redescription provides stopping rules for this process, e.g. Shepherd (1998), Figure 1.
4. The HTA dendritic diagrams (e.g. Figures 1 and 2 here) are simple for users, managers and process designers to understand, providing a visual reference that links directly to their own process knowledge and the descriptions provided in current reference works (e.g. Tracy, 1999) and current task instructions.

HTA does have limitations in the process outlined in this paper. The main one is that there is no assurance that all errors have been found, so that good practices may have been overlooked. However, there is little guarantee that alternative techniques would have produced more (or less) good practices. Overall, the use of HTA proved to be a useful technique for deriving good practices in the series of tasks comprising non-destructive inspection in civil aviation, but other techniques are not precluded.

Table 2. Part of Audit Checklist for 3.0. Apply Penetrant

	Yes	No	Comments
Spray			
• With the electrostatic spray, are the spray guns clearly differentiable?	☐	☐	________
• Can the feeds of the spray gun for water washable, or post-emulsifiable penetrants be cross-connected?	☐	☐	________
• Can the sprayer reach all surfaces?	☐	☐	________
Tank			
• Are the tanks clearly labelled?	☐	☐	________
• Is the handling system easy to use for part placement?	☐	☐	________
• Does the operator know when to agitate/turn the part in the tank?	☐	☐	________
• Does the carrier interfere with application of the penetrant?	☐	☐	________
• When the part is removed from the tank to allow it to drain for a specified time, is a drain area available?	☐	☐	________

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