Investigating the Use of RFID Technology in the Reverse Logistics of End-of-Service-Life Helicopters: A Hybrid Approach Based On Design for Six Sigma and Discrete-event Simulation

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ABSTRACT

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Concordia University and Bell Helicopter Textron Canada Ltd embarked upon a study to investigate the potential for using RFID technology in the reverse logistics of aircraft components, specifically those of end-of-service-life commercial helicopters. This study necessitated the consideration of the way in which contemporary commercial aircraft components (specifically those of helicopters) are handled during the reverse logistics process and the consideration of the peculiarities of the value proposition of end-of-service-life commercial helicopters that differentiate them in certain key respects from their fixed-wing counterparts.

The research presented in this thesis presents a proposed implementation framework for the use of RFID technology in the reverse logistics of end-of-service-life helicopters and provides a quantitative assessment (using discrete event simulation modelling) of the role which RFID technology can play in the ‘leaning out’ that reverse logistics process. The research uses a real-life case study of an actual helicopter commercial remanufacturing operation as a basis for the simulation modelling framework. The simulation modelling considers various, and increasingly complex, means of RFID implementation as part of a Return-On-Investment (ROI) analysis. One of the means of RFID implementation makes use of a novel RFID process for aircraft part identification which has been developed as part of this study: this innovative process makes use of a form of low-cost/low-weight RFID labels for identifying the component parts. This thesis also presents the results of the actual laboratory testing of these novel RFID labels which has been carried out as part of this study to assess the feasibility of implementing this innovative RFID process technology on helicopter structural components.

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I would also like to thank Mr Pierre Rioux (Manager of R&D Bell Helicopter Canada Ltd) for his willingness to sponsor this Engage project at a crucial time in my search for a value-added RFID-based research topic in order to complete my Master's degree studies. Additionally thanks are due to the company ("Operator A") which conducted the "remanufacturing' process of end-of-service-life helicopters which has provided the case study process and data which was crucial to giving a meaningful basis to the simulation study.

I would also like to acknowledge the contributions of Mr Hervé Bergeron, Mr Michael Vautour and Mr Paulin Tremblay of Bell Helicopter's Product Support Engineering for providing their expert knowledge in the estimation of detailed task times and the feasibility of tagging actual components for the case study reverse logistics process; Mr Pier-Alexandre Pelletier for providing guidance on the structural part manufacturing processes required to test the novel RFID technology under representative conditions and to the manufacturer of the prototype RFID assets for their timely provision of the prototypes for test.

DEDICATION

To Elizabeth, Emma and Rachael
Tom and Margaret

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AFRA	Aircraft Fleet Recycling Association
BHTCL	Bell Helicopter Textron Canada Ltd
CIISE	Concordia Institute for Information Systems Engineering
CTS	Critical to Satisfaction
DFSS	Design for Six Sigma
DFx	Design for "X"
EMS	Emergency Medical Services
FAA	Federal Aviation Administration
FL	Forward Logistics
FR	Functional Requirement
GEN2	Second Generation (Passive RFID technology)
HALT	Highly Accelerated Life Testing
HLN	High Level Need
MRO	Maintenance, Repair and Overhaul
NPS	Naval Postgraduate School (United States Navy)
NSERC	National Science and Engineering Research Council of Canada
OEM	Original Equipment Manufacturer
PAMELA	Program for Advanced Management of End-of-Aircraft
PSE	Product Support Engineering
R&D	Research and Development
RFID	Radio Frequency IDentification
RL	Reverse Logistics
RLSC	Reverse Logistics Supply Chain
ROI	Return on Investment
STC	Supplemental Type Certificate
TRL	Technical Readiness Level
VOI	Value of Information

CHAPTER 1 - INTRODUCTION

1.1 Background

Since the turn of the millennium there has been increased focus on the end of life management of aircraft (both fixed-wing and rotary-wing) and, inspired by initiatives and examples drawn from other industrial fields, researchers have begun to assess the specific reverse logistics aspects and challenges of aeronautical products in greater depth than before. This increased focus has led to a number of industry-sponsored collaborations for the reverse logistics treatment of end-of-service-life aircraft such as the Boeing-sponsored Aircraft Fleet Recycling Association (AFRA) [1] and the Airbus-sponsored Program for Advanced Management of End of Life Aircraft (PAMELA) [2] as well as by other entrepreneurial initiatives developed by industry. The AFRA organization has highlighted that there is a need for the entire aerospace industry (i.e. airframe and engine manufacturers, equipment suppliers and regulatory authorities etc.) to become better informed and more active in the field of reverse logistics. This need is becoming more acute due to the fact that the average service life of most aeronautical products is declining sharply, and many otherwise airworthy aircraft and powerplants are reaching the end of their useful/viable service life much sooner than previously expected [3]. Fortunately Original Equipment Manufacturers (OEMs) of aircraft (including helicopters) such as Boeing, Airbus, Bombardier and Bell Helicopter and other companies are responding to this emerging need.

Although many of the end-of-service-life challenges faced by the fixed-wing and rotary-wing industries are common there are aspects facing the rotary-wing community which are arguably unique to helicopters due to the nature of that class of product since the useful service lives of helicopters tend to be significantly longer that those of large fixed-wing commercial aircraft. There are a number of reasons for this, both from an engineering design and commercial market perspective: in the technical domain, helicopter fuselages operate unpressurized, so the useful service lives of the fuselages are greater; in the financial domain, although the direct operating cost of helicopters is high, helicopter fleet operators are not as aggressive in their fleet renewal programs in comparison with airlines and fleet operators of large commercial fixed-wing aircraft. Helicopter fleet operators will more readily look for opportunities to extend the service life of their existing fleet rather than adopt the policy common in the commercial fixed-wing community of refreshing the fleet with a 'buy new' policy, the latter tending to exacerbate the trend for progressively shorter service lives of fixed-wing products seen in recent years.

The willingness of large helicopter fleet operators to consider investing in their existing fleet of airframes rather than necessarily buying new aircraft creates obvious commercial opportunities for the commercial helicopter industry to find a business case for investing in airframe upgrade modification programs in order to extend the useful service life of large numbers of aircraft of a specific model by 'remanufacturing' the product to a more contemporary and higher performing variant. Bell Helicopter's current program to upgrade its substantial legacy fleet of Model 206L-1 and 206L-3 aircraft (which are no longer in production) to the performance level of the Model 206L-4 [4], a more capable variant which is still in current production, is a prime example of such an initiative and is of interest to researchers active in this aspect of the reverse logistics of aircraft.

The Concordia Institute for Information Systems Engineering (CIISE) approached Bell Helicopter Canada Ltd (BHTCL) with a proposal to explore the potential of using RFID technology to drive process improvement in the reverse logistics of aircraft components [4]. BHTCL was immediately interested by CIISE's proposal since the application of RFID technology within the aerospace industry is a technology which is gaining traction and acceptance, not only in the realm of manufacturing operations of new parts but also as a technology which provides valuable functionality when applied to on-aircraft components in service. Very quickly after discussions commenced with CIISE on the subject of the use of RFID in reverse logistics BHTCL cited the example of the Model 206L-1/L-3 upgrade program as providing a potentially very pertinent case study for the assessment of RFID technology in a reverse logistics context. As a result work commenced under the auspices of an NSERC Engage Grant [6] and the work presented in this thesis, and the prior work presented in [7], [8] and [9] are all direct results of this research.

1.2 Problem Statement and Research Objectives/Approach

Since the utilization of RFID technology in on-aircraft applications is still in its relative infancy there are a number of keys concerns with regard to its adoption on commercial helicopters:

1. Safety: the airworthiness of any technology fitted to a type-certified aviation product and the effects of that technology on the continued safe flight and landing of the aircraft (i.e. the potential effects on the occupants, other aircraft systems and the vehicle's structure) are of paramount importance;
2. Technical feasibility: the technical constraints of being able to use RFID technology in the confined space of an aeronautical vehicle such as a helicopter, with all the attendant problems that the materials which the vehicle is comprised of could have on radio-frequency based tracking systems;
3. Financial business case: due to the weight-critical nature of aeronautical products, any system installed on an aircraft has to 'earn' its right be installed on the vehicle by providing a sufficient

level of value-added functionality for the aircraft manufacturer and the operator of the vehicle in service. This is particularly true for a technology such as an RFID tracking system whose functional value added does not assist the vehicle to fly further, more quickly or to carry more payload: there has to be a proven operational value-added (at an appropriate cost/weight) associated with the system for the aircraft manufacturer and operator to see value in its incorporation on the aircraft.

The research presented in this thesis will develop a modelling framework to assess the impact of the use of such RFID technology in the reverse logistics network of aircraft components (specifically commercial helicopters). This modelling framework will have the following attributes:

1. It will employ a discrete-event simulation technique to model an actual reverse logistic process at "Operator A" (a real-life helicopter service center and helicopter fleet operator). As such it uses a real-life aircraft upgrade remanufacturing process as a case study, leveraging the actual measured data (process steps/task times/resources) to define and validate the simulation model. [Note: this case study is currently not time/resource constrained and could therefore benefit from further process optimization.]
2. It will use the simulation model to assess the impact of different, progressively more sophisticated, levels of RFID implementation on this upgrade process based upon practical, technologically achievable, RFID implementation scenarios.
3. It will develop these relevant scenarios by means of a "Design for Six Sigma approach" (DFSS).
4. The research study will also have the following objective: based upon available and representative cost data the business case for the various levels of RFID implementation will be

calculated. Specifically the work will provide an ROI model to assess the financial viability of each RFID scenario's technology solution business case.

One of the potential pitfalls for a project involving an assessment of any RFID implementation is the risk of over-estimating the extent to which the tag technology can reasonably be expected to be attached to, and remain attached to, the components being tracked. This is especially true of components on transportation vehicles (e.g. automobiles, locomotives and aircraft): these vehicles operate in particularly harsh environments in terms of temperature, pressure and vibratory extremes. Furthermore, the physical size of the components themselves will inevitably create challenges and constraints on the type of RFID tag which can be attached to them (and the size of the tag which can practicably be used). As such this project strives to remain realistic in its assessment of what components can be tagged and as such try to avoid being too ambitious in any assessment of precisely how many on-aircraft components (and which type of components) can realistically be tracked via RFID. In order to achieve this the project developed, as a result of its Six Sigma problem formulation phase, a secondary (empirical) aim of assessing a novel type of RFID technology for aircraft part identification which has been identified and developed during the course of this project. The genesis of the idea for exploring the development of this part identification RFID technology arose as a direct result of the 'thought process' of the solution identification phase of the DFSS approach adopted to tackle the current research problem. The technology involved relates to the development low-cost, low-weight, printable label-type RFID tags for structural components: these labels would be capable of withstanding the harsh industrial manufacturing and in-service aircraft environments. The assessment will involve examining the readability of such label-type RFID tags after being exposed to temperature and pressure extremes. The research described in this study provides a test plan and results appropriate for assessing the viability of the label-type tags on structural components and Chapter 6 will present these results.

By the end of this study the project will draw relevant conclusions and recommend appropriate next steps based upon the aforementioned modelling framework research about the potential impact of RFID in the specific reverse logistics application of remanufacturing end-of-service-life helicopters. Additionally the impact of this technology on other aspects of the vehicle life-cycle (forward logistics) will also be commented on in the context of future work.

1.3 Thesis Organization

The remainder of this research thesis is organized as follows:

Chapter 2 presents a literature review covering general aspects of reverse logistics; specific aspects of reverse logistics as it relates to aircraft and helicopters; the adoption of RFID technology in reverse logistics with particular emphasis on aircraft; general simulation modelling approaches and the assessment of the ROI of embodying RFID technology. In the context of the empirical aspect of the project the literature review will also examine the prior use of RFID technology in harsh aviation environments.

Chapter 3 presents a more refined and detailed definition of the research problem based upon the insight gathered from the findings of the literature survey. This chapter will show how the precise problem statement's formulation matured as the research project progressed.

Chapter 4 presents the proposed approach to the solution of the previously defined research problem, using a “Design For Six Sigma” (DFSS) methodology as a framework for tackling the problem solution.

Chapter 5 presents the discrete-event simulation modelling of the specific industry-based case study which will be used to evaluate the potential contribution which RFID technology might make to the technical reverse logistics problem being investigated. The simulation modelling approach will enable the impact on the process of different scenarios of RFID technology implementation to be assessed: these scenarios were generated by the DFSS problem solution methodology.

Chapter 6 presents the empirical results of experimental testing carried out as part of the current work in order to assess a novel practical application to using RFID technology in the tracking of component parts by means of low-cost/low weight, robust labels for structural parts. This RFID technology must be capable of withstanding the harsh environments to which the associated parts could be subjected during manufacturing and in service.

Chapter 7 presents the conclusions drawn from the research findings and makes recommendations for future research work which could be carried out to progress the technical readiness of the use of RFID technology in the context of its use in on-aircraft applications and as part of the track and trace of parts during their original manufacturing process.

CHAPTER 2 - LITERATURE REVIEW

2.1 Overview

This chapter aims to present a literature survey of the main themes of the research work that are pertinent to this study and these key themes are presented below:

- Definition of the term "reverse logistics" in the context being studied
- A general description of RFID technology
- Specific considerations for the use of RFID in aviation
- Adoption of RFID in the reverse logistics of aircraft
- Simulation modelling approaches for the RFID implementation methodologies
- Using the simulation model to assess the return on investment (ROI) of RFID

The subsequent sections of this chapter examine these themes in more detail. In this discussion the term "reverse logistics" will generally be abbreviated to "RL".

2.2 Reverse Logistics – General Discussion

2.2.1 Reverse Logistics – A Definition

Over the past twenty years there has been a progressively greater focus given to the field of study which we now know as "reverse logistics" and, while there is much research activity that remains to be pursued in this field, the discipline is now mature enough to have established a valuable body of research work. The key researchers have defined progressively more comprehensive definitions for the term "reverse logistics" (RL) and notably Rogers and Tibben-Lemke [10] provided a very useful starting definition as follows:

Definition No. 1 [From Reference #10]

"The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal."

Given this context for RL the work of Aït-Kadi, Chouinard, Marcotte and Riopel [11] provides a comprehensive review of the engineering and management of sustainable RL networks and in their work they note that:

"The solutions implemented over the past few years are aiming much more at maximizing recycling rather than extending the product lifetime."

The key point in this observation being that such an approach will necessarily consume energy in order to *"...recover raw material from existing products to build new products."* Their observation is that, in contrast, a more sustainable approach would be to consider methodologies which would prolong the product's useful service life rather than recycling it. The helicopter upgrade approach being implemented by Bell Helicopter and examined in this research study directly addresses this point.

Reference [11] further refines the definition of RL proposed by Rogers and Tibben-Lemke and adopts the following definition within that study and considers the process of RL as:

Definition No. 2 [From Reference #11]

[The] *"Process of planning, implementation, and controlling which aims at maximizing the creation of value and clean disposal of reverse product flows, by efficiently managing raw materials, in-process inventory and the finished goods and the relevant information, from the consumption point to the point of origin".*

This definition's incorporation of the idea of maximizing value creation rather than simply recapturing it relates well to the context of the current study and represents a better overall process definition than that of Rogers & Tibben-Lemke. In order to refine the Definition #2 further, to the specific case of upgrading aviation products with the aim of extending their useful service life, a further modified version of the above definition is proposed within the framework of this study presented in this thesis and so considers the RL process as:

> **Definition No. 3** [Defined by this thesis]
>
> *"The process of planning, implementation and controlling which aims at maximizing the value proposition and the sustainable disposal of the reverse product flow, by efficiently managing the source materials, in-process inventory, the finished goods, and the relevant process information, from the product return point to the point of value recovery".*

In this sense the "source materials" are not "raw" in that they may be current in-service production aircraft assets and the "consumption point" in Definition #2 can be considered as the "product return point" of Definition #3. Furthermore the "point of value recovery" in Definition #3 may not be the original point of manufacture (origin), or even the same company, but may instead be an appointed agent or service facility. In the context of the helicopter upgrade the product return point and point of value recovery may in fact both be the same location: an approved aircraft service facility. The helicopter upgrade process which is the basis for this research project fits very well with this more sophisticated definition of an RL process: the helicopter upgrade process plans, implements and controls activities which aim to maximize the economic value of the helicopter and the sustainable disposal of the disassembled components. The upgrade process efficiently manages the helicopter components, its in-process inventory and the upgrade information at the service facility.

Reference [11] has defined a generic process for the review of any RL coordination system, based upon the prior work of a number of other researchers such as Giuntini & Andel, [12], Rogers & Tibben-Lemke [10], and Schwartz [13]. This process is shown in Figure 2-1. This process mapping lends itself well to the helicopter upgrade RL process studied in the current work.

The business decision to upgrade a helicopter is based on a combination of factors:

1. Cost-benefit of upgrade versus buying a new airframe
2. The lead time in which a new aircraft would be available from the OEM manufacturer
3. The owner/operators attitude to running a contemporary fleet.

Once a decision has been made to upgrade the aircraft capabilities the airframe enters the generic RL coordination process highlighted in Figure 2-1, adapted from the version presented in Reference [11].

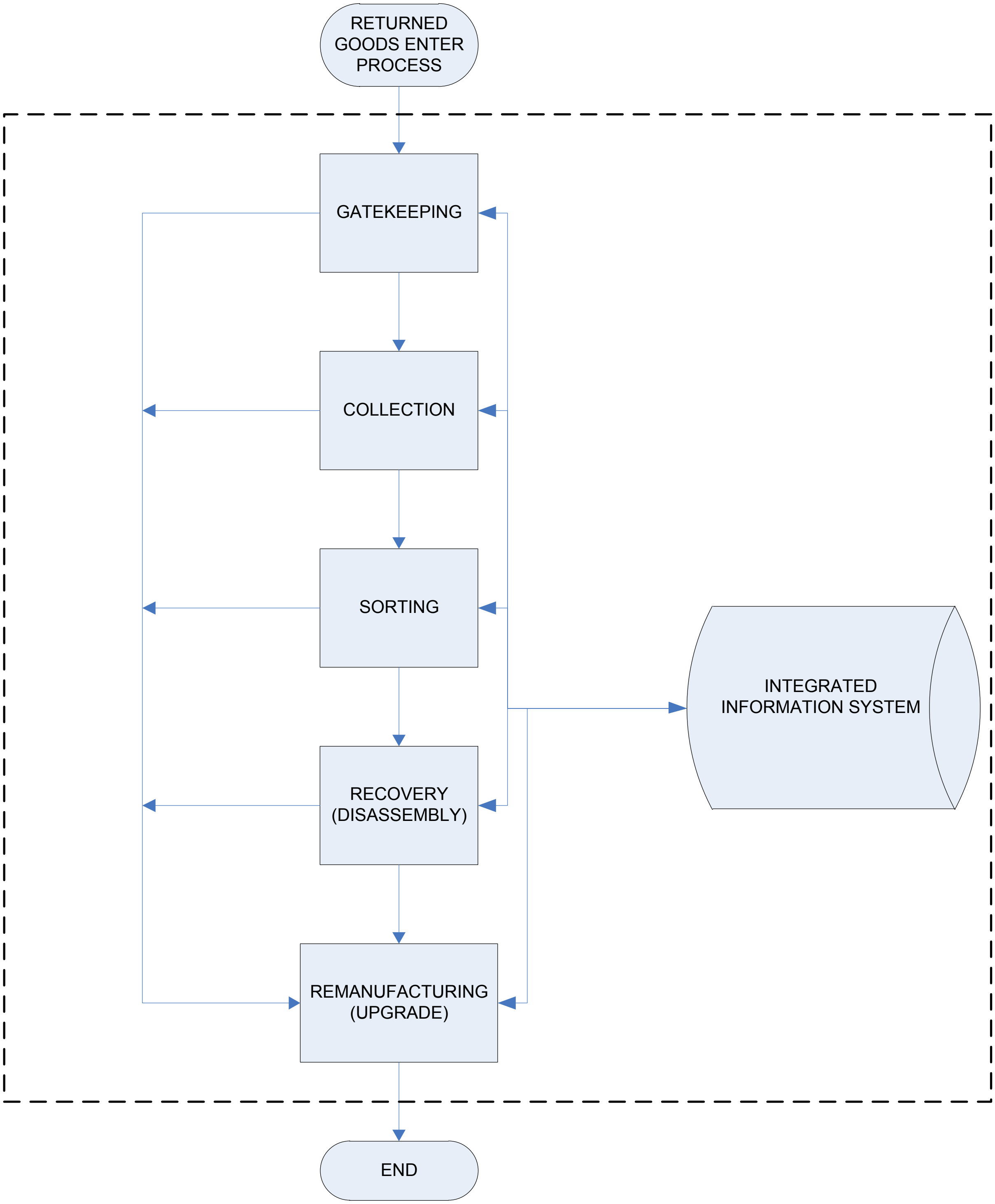


Figure 2-1 – Generic Process for Reverse Logistics Coordination (Adapted from [11])

The first "Gate keeping" step obviously controls the product entry into the upgrade system and in this context would represent the acknowledgement (by the helicopter OEM, or their appointed agent (i.e. a third-party Service Centre)) that the candidate aircraft's configuration is eligible for the upgrade: this decision step is based upon the aircraft's model and serial number. This "eligibility" will likely be dictated by two factors: firstly, the existence of a commercially available upgrade package or "kit" being offered by the original aircraft manufacturer (i.e. the instructions for which are formalized via a published helicopter manufacturer's Service Bulletin) under the auspices of the original aircraft type certificate; or, secondly, the availability of an upgrade offered in the aftermarket by an independent organization (distinct from the original OEM) who holds a Supplementary Type Certificate (STC) for the modification required. The second, or "Collection" stage of the RL process involves the transportation of the helicopter to be upgraded: normally this will be done by simply flying the subject vehicle (if it is airworthy) to the facility where the upgrade will be carried out, and this may be performed by the customer's own pilots or by pilots from the upgrade centre offering the service.

The third and fourth stages of the process ("Sorting" and "Recovery") are much more involved than the prior to two steps, and the "Recovery" (also known as the "Treatment" phase in Ref [11]) process is particularly complicated in the context of a helicopter upgrade and comprises a number of sub-processes. As described in Reference [11], and presented in Figure 2-2, the sorting step does indeed validate the information obtained at the Gate-keeping step, however it is very unlikely that the Service Centre will refuse the 'returned' product, although some communication with the customer will be required to confirm the cost of the upgrade based upon the "as delivered" configuration of the aircraft. (Note: In the context of returned products in other industries it is quite possible that the returned asset may be frequently/routinely refused entry due to its physical/cosmetic appearance and/or its perceived residual/intrinsic value. This is much less likely in the case of an aircraft or helicopter. Hence a modified sorting step process map is presented in Figure 2-2 to reflect the actual process applicable for the helicopter upgrade.)

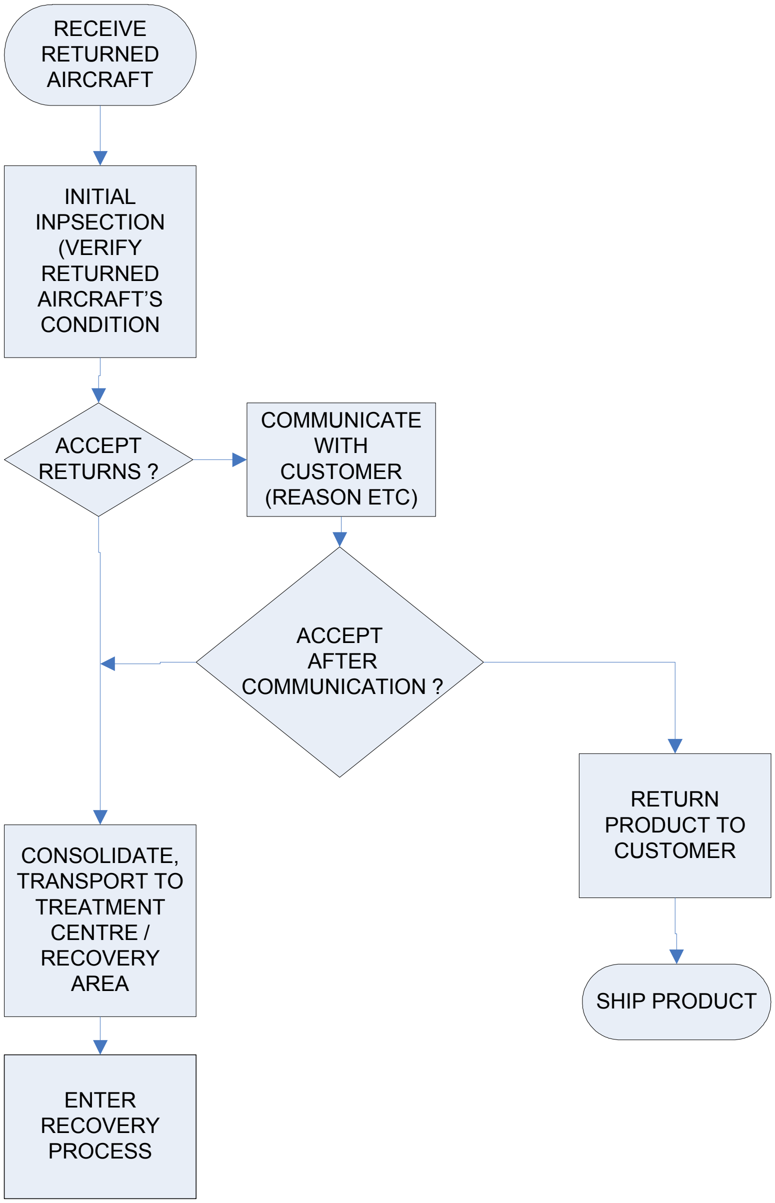


Figure 2-2 – Process for the Sorting Step (Adapted from [11])

The fourth step, the “Recovery” step (also known as the “treatment” or “remanufacturing processing” step) is, as will be seen from the detailed process mapping in Chapter 5 the most demanding stage in the overall RL process and comprises the disassembly, inspection, inventory management and recovery option sub-processes for all the individual components, systems and structural parts of the aircraft. In this step these components, systems and structural items are disassembled from the as-delivered aircraft on which the upgrade is to be performed. In particular the case study presented in Chapter 5 constitutes quite an invasive disassembly (or "parting out") process in order to strip the aircraft down to the basic carcass upon which the aircraft reassembly (upgrade) process will subsequently be carried out. Again the work of [11] provides a very pertinent process map, and the version below (Figure 2-3) represents a modified version which presents the processing activities which are relevant to the helicopter recovery process.

2.2.2 Contribution of RFID in Reverse Logistic Supply Chains

Some studies have been performed which comment on the contribution of RFID in the Reverse Logistics Supply Chains (RLSCs): these studies have considered industries quite separate from the aviation sector. A previous study by Lambert, Riopel and Abdul-Kader [14] identified that there has been some research into the role that RFID technology can play in the reverse supply chain: the sense is that RFID can provide a means of optimizing the RL network and assists with some of the specific challenges that differentiate the RL network from the forward logistics network. Asif [15] in particular provides a valuable overview of the role RFID can play in this domain: in summary that work draws a distinction between the "uncertainties" present in the forward logistics and reverse logistics supply chains. These are described and the work defines 5 principle uncertainty categories. Further, it explains the impact of RFID in these five areas and defines a conceptual model for reducing these uncertainties using RFID. Additionally the work proposes three reasons why RFID has not been

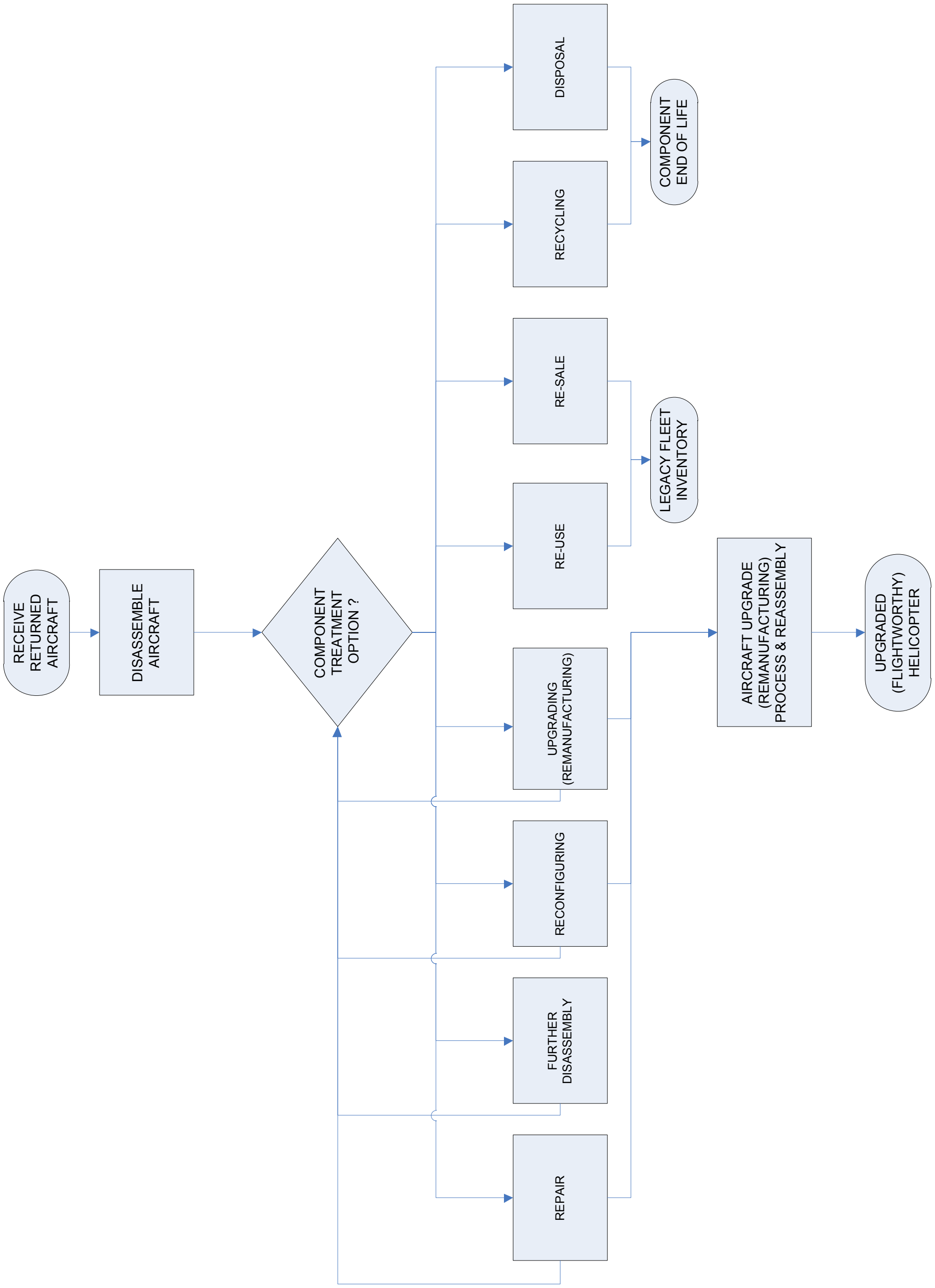


Figure 2-3 – Process for the Recovery Step (Adapted from [11]) adopted in reverse logistics supply chains. The five uncertainties are:

1. Quantity (the volume of products, or “returns”, which could be input to the RLSCs).
2. Variety (the differing standards, configurations of the products input to the RLSCs).
3. Quality (the conformance to specification of the returned products): this can be highly variable in the context of our helicopter example.
4. Cycle time (the cycle times for the treatment of returned products)
5. Market trends (i.e. the fact that the uncertain nature of the market demand at a given calendar time will influence the flow of the RLSCs).

These are all legitimate risks, or uncertainties, which are present in the RLSCs generally and some of them have a direct relevance to the helicopter upgrade program being studied. Taking each of these in turn:-

I. <u>Quantity</u>

Many researchers such as Jayaraman, Ross & Agarwal [16], and Parlikad & McFarlane [17] have identified that uncertainties in the RLSCs are principally due to a lack of information and especially due to:

1. the timing and quantity of the returned products in the disassembly process,
2. the ability to recover material. In Chapter 5 it will be shown how the RFID technology can play a contributing factor to mitigate the latter risk in this regard, particularly with respect to timely inventory control and spares procurement planning.

In the context of the helicopter upgrade this uncertainty, at any given time, is relatively low since it is a “niche” market, the overall number of candidate aircraft for upgrade is relatively small (compared to automobiles for example) and so the market is relatively predictable **[Low Risk] [RFID Low Impact]**

II. Variety (Configuration)

In most RL processes the term "variety" refers to the wide differences in the brands, models, products and commodities which may be input to the process: for example, product returns to an on-line consumer electronics merchandiser. In the context of a helicopter upgrade program the brand and model are well controlled, but the precise "configuration" of the products are likely to be markedly different, even for vehicles that were produced at approximately the same calendar time. At first glance readers that are not familiar with the aviation industry may find this very surprising however there are clear reasons for it: aircraft and helicopter configurations at new production are continually being changed with the aim of improving the basic design functionality, the incorporation of airworthiness (i.e. safety) improvements and the embodiment of design changes driven by the need for manufacturing easement. In the case of the helicopter models affected by this upgrade program there were over 40 progressive and different new production configurations for the basic aircraft model. Additionally, and arguably even more significantly, new production vehicles can routinely be heavily "customized" with Kits, or modification packages (both those offered by the OEM and those offered by independent companies in the aftermarket) depending upon particular customer requirements which can be heavily influenced by the operational role the helicopter may fulfill (i.e. corporate, law enforcement, emergency medical services (EMS), oil and gas producers, leisure etc.). Furthermore, over a service life of 25 to 30 years (or more) the aircraft may change owner a number of times and could be significantly modified as it passes from one owner to another and from one role to another, on multiple occasions over its service life. Helicopters can be quite highly customized products, so no two returned vehicles are necessarily in the exact same configuration **[High Risk] [RFID High Impact]**

III. Quality

Although in most cases the helicopters to be upgraded will be fully “airworthy” and functional upon entry into the RL process an invasive teardown of mature air vehicles such as these will necessarily involve a comprehensive inspection of components, systems and structure which will necessarily reveal non-conformities (Component malfunctions, wear, corrosion etc.). While RFID will not in itself provide a metric of quality, for the vast majority of the disassembled components the presence of RFID will enable the findings of the RL inspections to be directly and more efficiently associated with the individual components concerned. There is however a key category of helicopter components (and this is equally true for fixed-wing aircraft) where the RFID technology can potentially yield tremendous benefits in terms of “leaning out” the RL process: that category is the “lifed parts”. In FAR43.10 [18] a “lifed part” is defined to be:

> *“Life-limited part means any part for which a mandatory replacement limit is specified in the type design, the Instructions for Continued Airworthiness, or the maintenance manual.”*

This is a critical area where RFID technology can yield significant advantages for the RL process of lifed parts since the ability of the parts to ‘self-identify’ themselves and in so doing provide accurate, detailed and timely information about their configuration (modification standard) and in-service history to the technicians disassembling the product. **[High Risk] [RFID: High impact on certain part categories]**

IV. <u>Cycle Time</u>

Any variations in the as-received quality (revealed by inspection during disassembly), and variations in the as-delivered configuration of the vehicles to be upgraded will necessarily affect the cycle time required for the treatment of returned products, in large measure due to the inventory levels and the resulting quantity of the spare parts which may be required to replace any defective components. Therefore the timely <u>identification</u> of configuration variations and quality issues in the RL process would represent a Lean tool within the disassembly process. This risk is very dependent upon the three prior uncertainties and therefore, given the large uncertainty associated with “Variety” and “Quality”, can be considered to represent a **High Risk.** **[RFID: High Impact]**

V. Market Trends

Arguably this is not as dynamic a factor in the case of an upgrade program for helicopters, although it will represent a secondary factor. Generally speaking the volume of fielded helicopters is not as dynamic as for mass produced items such as consumer products, and the business case and market demand for the upgrade program will therefore be relatively stable in the short to medium term. This being said, significant economic (or safety) factors affecting the market for a particular model of helicopter could suddenly influence market trends (e.g. crude oil prices or the identification of safety-related design concerns associated with a particular model).

Although this is a consideration with helicopters it is arguably much more of a driver in the context of larger commercial fixed-wing aircraft fleets where the retirement of a large number of aircraft by a major airline can have a dramatic effect on the residual value of an aircraft model. In a helicopter context it therefore represents **Low Risk**. **[RFID: No Direct Impact]**

Having identified from the aspects above that there are clear beneficial impacts that RFID can have on most of the RLSC supply risks the case for the adoption of RFID in RL has not been without challenges. The work of Asif [15] goes on to identify what that author terms as "obstacles" to the adoption of RFID in RLSC. The main obstacles discussed in that work are grouped below under three main subject headings:

1. Quality and processing sequence
2. Collection points and differing standards
3. RFID and the global market (which are in turn categorized as follows)
    a. Different compliance requirements for different OEMs
    b. Lack of an international standard
    c. Cost: tags are still more expensive than other technologies and certainly than printed labels
    d. Reader collision problems
    e. Customer acceptance

More will be said on this in Chapter 5.

2.2.3 Reverse Logistics – Emphasis on Product Service Life Extension

Tibben-Lemke [19] discusses the life of a product from a sales and marketing perspective rather than an individual product use perspective and, based upon the work of other authors in the field such as Kotler [20], states that the product's sales life cycle can be regarded as being divided into several phases and that the work of Kotler [20] highlights that a product can be 'reincarnated' to produce "partially new products [that] do all that an existing produce did, [but] with additional features. They compete with the old product, but extend the market for the item overall". This scenario would be represented by the following sales life cycle (see also Figure 2-4)

1. Introduction
2. New Sales Growth
3. Maturity
4. Decline
5. Recycle

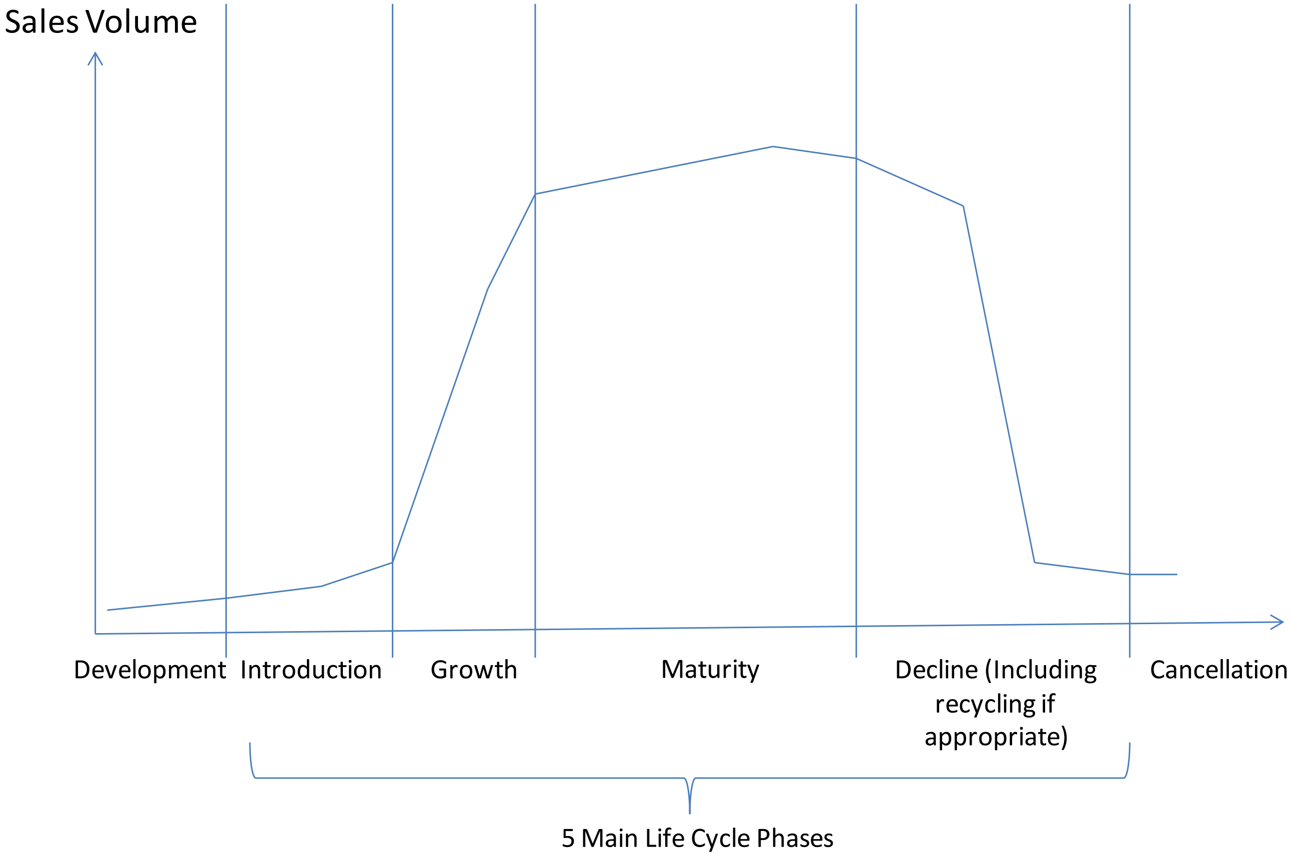


Figure 2-4 – Stages of Product Life Cycle (Adapted from [19])

The helicopter upgrade scenario analyzed in this research study fits exactly into this category identified by Kotler. Obviously this business model does not result in more original sales for the helicopter manufacturer but does extend the product's life in the market which provides an ongoing revenue stream for spares, in-service modification upgrades, kits, life extensions and potentially the engineering services required to carry out the aircraft modifications. For many commercial helicopter products the OEM manufacturer's profit margin from the sale of the original (new) aircraft is significantly less than the main revenue stream, which is the commercial mark-up on spares, in-service modifications and engineering services sold for profit to operators during the product's service life. Any scenario which extends the existing helicopter's service (and therefore revenue-generating) life, and which helps prevent new competitor products penetrating the market can be viewed as being as important as a new product sale. In this light, any value-added enabling technology such as RFID which is used in the upgrade scenario, at competitive cost, is worthy of consideration.

At a strategic level some authors, namely Rogers & Tibben-Lemke [10], have analyzed the barriers to executing reverse logistics: in some cases this has been principally due to reluctance at the OEM companies simply because a RL strategy is simply not regarded as having a high enough priority in the companies concerned. The same authors cited a number of other "barriers to reverse logistics" and these included a "lack of reverse logistics information systems" due to the fact that "Few firms have successfully automated information relevant to the return process" and that "Most return processes are paper-intensive". It is believed that the actual case study in Chapter 5 will show the way in which RFID technology can help to further overcome this barrier.

The end-of-service-life handling treatment of products in the aviation sector has been receiving increased attention from a research perspective particularly since the turn of the millennium: the author de Brito has been active in the field [21]. The world's fleet of commercial aircraft is increasing and the statistics from AFRA [3] predict that the average service life of an aircraft is falling and that the current world aircraft fleet will see an increasing number of returns of existing aircraft due to cost of ownership, societal and other business factors. The latter factors can be summarized as follows:

- New aircraft are more efficient in terms of operating cost and fuel consumption [22]
- Corporate image: airlines operating in the higher market segments tend to operate younger fleets due to their corporate image being a driver rather than purely operational reasons.
- Significant changes in the nature of the leasing market for second-hand aircraft since the millennium.

After 2 years of being 'parked' (i.e. being in storage) and aircraft only has a 5% chance of ever flying again [23].

Although there has been increasing awareness by the major aircraft airframe manufacturers about the end-of-service-life recovery of their products, which has led to the creation of the AFRA and PAMELA initiatives, this has not been as big a driver for helicopters. However, as De Brito [21] points out *"[a] more rare approach is to dismantle the airplane for remanufacturing…"*. One of the objectives of this study is to examine this approach in the context of helicopters.

2.3 Description of RFID Technology

The purpose of this section is to give a brief description of the manner in which Radio Frequency (RF) technology works and the way in which the science can be used more specifically in the context of **R**adio **F**requency-based automatic **ID**entification systems (RFID). Since, for reasons detailed in Section 2.4, generally only passive RFID technology is pertinent in the context of on-board systems and components of aircraft and helicopters the description of the technology will be limited to that passive form only. There are a number of texts which describe the physics of RFID in detail [24]. Figure 2-5 shows the basics elements of an RFID system and the four main components that it comprises: namely the tag (also known as a transponder), antenna, reader and "Middleware".

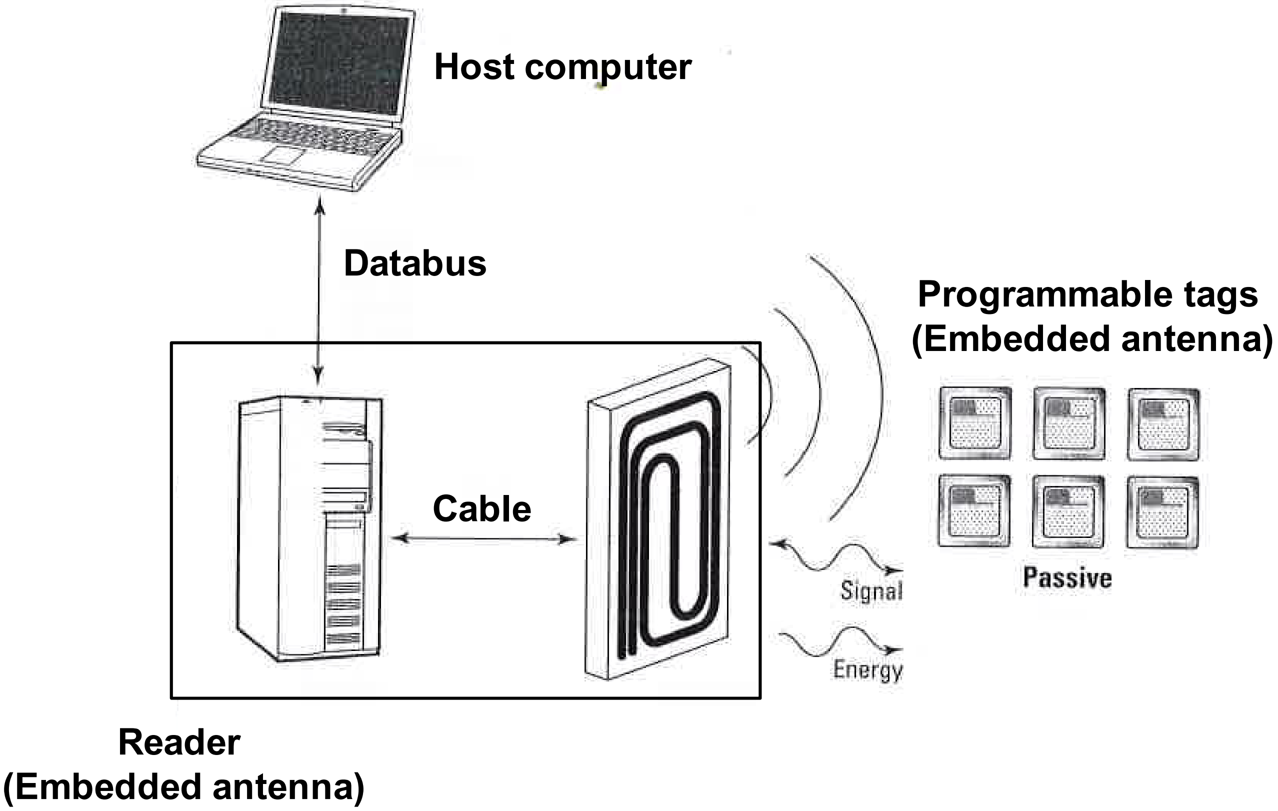


Figure 2-5 – Basic Components of an RFID System (Adapted from [24])

The passive tag is energized (activated) when it is exposed to a field of electromagnetic waves in the radio frequency (860 to 960 MHz) which have been generated by an antenna/reader system. The tag comprises of an external protective case (which can take many forms depending upon the application for the tag) and an internal "inlay", which comprises an antenna and computer chip (memory area) as shown in Figure 2-6. The computer chip is programmed with information that uniquely identifies that tag. It is this information which is transmitted (or back-scattered) to the system antenna/reader when the tag is activated by the system antenna's original signal. Passive tags can only transmit when they are energized by a system antenna since the tag does not contain a power source of its own (hence the term “passive tag/transponder”). As a passive tag moves into the radio frequency field emitted by a system antenna it will receive enough electromagnetic power to activate its memory chip and back-scatter all the information (which may be encrypted) contained in its memory back to the system antenna. The signal received by the system antenna from the tag is interpreted by the reader (also known as the transceiver). The reader controls the system antenna and decodes the signal received from the tag and passes/transmits that information on to the host computer system. The reader can also transmit signals to the tag to allow additional or revised data to be stored on the tag’s memory.

Figure 2-6 – RFID Tag and Inlay (comprising antenna and computer chip (memory))

The antenna which emitted the original radio frequency field receives a programmed response from the tag and conveys that signal to the system reader (also known as a transceiver).

2.4 <u>Specific Considerations for RFID in Aviation</u>

There is already a wide body of published literature describing the uses and benefits of RFID technology in various non-aviation industries and market segments: substantial use has been made of this auto-ID technology in the retail industry: the classic example being Wal-mart’s mandate for its major US suppliers to fit RFID technology to pallets and cases [43] for more effective inventory control purposes. Additionally, Section 2.6.2.2 describes the use of RFID in the logistics industry, specifically in the domain of military equipment.

There are obvious concerns on the part of the world's civil aviation regulatory authorities regarding RFID and they relate primarily to the need to ensure that the RFID technology does not detrimentally interfere with an aircraft's existing avionic and electrical systems, and also the need to be satisfied that the RFID system's integrity will not, in turn, be compromised by any of the aircraft's on-board systems. The adoption of RFID technology on aircraft applications has however made sufficient progress to the extent that there is already a Federal Aviation Administration Advisory Circular [25] on this subject which stipulates that the nature of the technology which can be used on in-service commercial aircraft is restricted to second general passive tag technology and certain categories of active tag technology. Passive tags are by their nature cheaper than active tag technology. In the case study represented in Chapter 5 only the use of passive tag technology is discussed.

2.5 Adoption of RFID Technology in the Reverse Logistics of Aircraft

There is only a very modest body of published research in the domain of the use of RFID technology in aviation. The specific applications of the technology in the aviation sector have been restricted to a few notable examples in the context of aircraft (fixed-wing and rotary-wing) and engine systems' maintenance:

- Boeing: life vests and oxygen bottles
- Airbus: life jackets and seats
- Turbomeca: "Boost" system used on their "Arrias" engine

- Airbus Helicopter (previously Eurocopter): the tracking of critical components on the "Dauphin" helicopter. [26]
- Bell Helicopter: in-service tracking of serialized line replaceable units (LRUs) on the new Model 525 ("Relentless") helicopter, currently under development. [Note: An LRU is any modular system component which is designed to be easily removed and replaced during maintenance or overhaul activity.]

In a similar way to Boeing, Airbus [27] has used RFID technology to tag cabin equipment (i.e. life jackets and seats) on its A330 and A340 aircraft fleets since 2008.

No published information exists about the use of RFID technology in the specific context of the reverse logistics of aeroplanes, and certainly not helicopters. There are a number of obvious reasons for this: firstly, in the near to medium term (say the next 5 to 10 years) the aircraft which are going to be subjected to RL disassembly are airframes which have been constructed within the past 5 to 10 years (i.e. have little or no RFID technology on board); secondly, no fielded system takes an holistic approach at the component, system and structural part levels, and thirdly, to-date there has been an absence of a concerted effort across the industry to examine the value proposition of RFID tagging for this purpose (i.e. a study that examines the cost savings, on-aircraft weight impact, and technical feasibility of the various forms of RFID tagging that could practicably be carried out to make the technology's implementation worthwhile). This study aims to make a contribution to addressing this knowledge gap.

Outside of the aviation context the work of Miertschin and Forrest [28], Ferrer and Dew [29] and Ferrer, Heath and Dew [30] have examined the use of RFID technology in improving the efficiency of a remanufacturing application, based upon an actual US Department of Defense (DoD) case study, using discrete-event simulation modelling techniques: this prior work is closely aligned with the current work presented in this study, but there are marked differences. The work of Ferrer references the definition by Lund [31] of remanufacturing as:

> ***Remanufacturing Definition*** *[Reference #31]*
>
> *"[A]n industrial process in which worn out products are restored to like-new condition. Through a series of industrial processes in factory environment, a discarded product is completely disassembled. Useable parts are cleaned, refurbished, and put into inventory. Then the new product is reassembled from the old and, where necessary, new parts to produce a unit fully equivalent – and sometimes superior – in performance and expected lifetime to the original product."*

The work of Ferrer & Dew [29] proposed that there are a number of questions to be addressed in considering whether RFID should be adopted widespread in the US DoD's remanufacturing operations:

1. What type of RFID technology should be employed?
2. When should assets be RFID tagged at source, and when should they only be tagged upon arrival at the remanufacturing facility?
3. What characterizes the remanufacturing facility that means it would benefit from using RFID technology to track assets?

In the context of the RL of aircraft (and specifically helicopters in this present study) the answers to the first two questions are readily obtained by virtue of the assumptions used/implicit in the study:

1. The assumption is that ("second generation" GEN 2 passive RFID tag technology will be employed (in line with the FAA's published Advisory Circular [25]) (Bar-coding is used on the latest generation of Bell Helicopter's part labels (see Section 5.1) but there is a very limited quantity and type (quality) of information that can be associated with a particular (unique) part associated with this identification method: hence the belief that passive RFID technology can be an enabler for more item-specific information to be associated with part and made readily available to the mechanics/aircraft operators, with the added advantage of being a non-line-of-sight technology at an acceptable read-range.)
2. The assumption is that the aircraft assets will arrive pre-tagged.

The first assumption is based upon the fact that, as described previously in this section, for helicopters currently under development at Bell Helicopter, RFID tagging at the component level is being implemented at new production, with the intent that the tag will stay with the part, and record valuable service life data, during the entire in-service life of the tagged part. Prior research by Kulkarni, Ralph and McFarlane [32], and Zikopoulos and Tagaras [33], has proposed that prior tagging of the assets can, in some instances, provide information about the part/system which will be of value during the disassembly process as part of the remanufacturing/upgrade process. These researchers have proposed that, since there is a high level of uncertainty with regard to the "quality" of the assets entering the RL process the information about the prior history of the part that is stored in the RFID tag associated with the part can provide actionable intelligence that will help with the sorting process. As discussed previously in Section 2.2.2 this certainly applies to the "lifed" and "serialized" components used on aircraft and helicopters. The work of Ferrer & Dew [29] stated that the prior work of Kulkarni and Zikopoulos [32, 33] had produced significant insights in this respect, as follows:

1. The VOI (Value of Information) from RFID technology using passive tags increases with the degree of likely component quality.
2. The value of presorting using RFID-based component data is dependent upon a number of factors: disassembly cost; holding (inventory) cost; sorting/testing cost; accuracy of alternative sorting/testing techniques. In all cases if the latter costs are high, and/or the accuracy of alternate sorting/testing procedures is low, the RFID-based information will add value. (One of the aims of the current study is to quantify how much this is true).

This leaves the third question: "*What characterizes the remanufacturing facility that means it would benefit from using RFID technology to track assets?*" as an issue to be addressed by the current work. In the case of the helicopter upgrade process analyzed in Chapter 5's case study the parts removed from the helicopter, which can legitimately be used as part of the upgraded configuration, must remain associated with the original vehicle: they cannot (in line with accepted aviation practices) routinely be used on another upgrade vehicle which may belong to another customer. This is clearly an aspect where RFID technology would be beneficial

Notably the work of Ferrer *et al.* [30] mentioned previously uses a discrete-event simulation model to analyze the way in which RFID technology can help improve the efficiency of the remanufacturing operation. More will be said on this in Section 2.6 (Simulation Modelling Approaches in Reverse Logistics).

2.6 Simulation Modelling Approaches in Reverse Logistics

2.6.1 Why is a Simulation Modelling Approach Valid in this Case?

Before embarking on a review of the existing simulation modelling approaches on RFID in RL it is appropriate to consider why such an approach is worthwhile in this case. Firstly, within the overall philosophy of "Design for Six Sigma" there is a well recognized and valued place for the use of simulation approaches in the prototyping phase.

A discrete-event simulation model of the case study scenario will be presented and analyzed in Section 5.2. A simple spreadsheet-based approach could have been used to provide an indication of the impact, and therefore potential business case justification, for the adoption of RFID in the environment being studied: this approach would however be insufficient, and the decision to adopt a discrete event simulation approach adds value for the following key reasons:

1. Various levels of RFID implementation sophistication need to be assessed;
2. Their merits compared and contrasted;
3. The contrast can be done much more efficiently (cheaply, quickly) using simulation techniques than by an actual implementation.

A number of researchers have used simulation approaches to examine the effect of RFID technology on RL and RL processes and their work is discussed below.

2.6.2 Existing Simulation Modelling Approaches to RFID in RL

While there has been some published prior work on RFID in RL that has employed simulation techniques in order to further the research the scope has been very limited and has not been based upon an actual case study approach: this is another area in which the current study aims to add value. The previous non-CIISE based work will be discussed in Section 2.6.2.2. There are three other complementary studies to the current one which were also carried out at the CIISE and which were associated with the use of RFID in RL: these will be addressed in the next section.

2.6.2.1 CIISE Studies on RFID in RL

The three recent CIISE-originated studies complementary to this current one and which have been carried out over the last two years are the work of Adetiloye [7], Sandani [8] and Dejam [9].

The work of Aditloye used a discrete-event simulation modelling approach and focused on the development an analysis of an overall business case for RFID being applied to end-of-service-life aircraft parts where the aircraft arrived for disassembly without any RFID technology applied to any of the components: the tags were assumed to be applied during the component disassembly process. The three tagging scenarios considered were item (i.e. component) level, case level and pallet level. Not surprisingly, since the aircraft was <u>not</u> assumed to arrive “pre RFID tagged”, the analysis ultimately concluded that there was no viable business case for RFID implementation, however the study did point out that the potential for RFID to yield process savings was greater than existing bar-coding technology although the initial investment required for RFID was a financial impediment.

The study carried out by Sandani [8] used the overall case study example used in this current study, which is also used in that of Dejam [9], although Sandani’s work did not use the detailed task time estimates available to Dejam and the current study (Appendix One). The work of Sandani concluded that RFID implementation was effective in reducing the aircraft’s disassembly time.

The most recent prior work by Dejam [9] used the same case study data used in Chapter 5 of the current study presented in this thesis. Dejam's work made an overall comparison of different simulation modelling approaches whereas this study makes are more in-depth analysis using a discrete-event simulation technique alone. Dejam concluded that, for all three modelling approaches, the implementation of RFID technology will yield time savings of approximately 10% over the non-RFID case. Chapter 5 will discuss these findings further in the context of the present study

One common feature which these latter two previous studies share is that they all assume that every component disassembled from an aircraft can be RFID tagged. (The work of Aditloye also made this assumption in one of his modelling scenarios but also compared it to case and pallet-level tagging). The current study presented in this thesis has not made this assumption: the state-of-the-art of RFID technology and the size, geometry and in-service handling practices of aircraft components during their operational life does not support the assumption of tagging the entire family of disassembled components as being a viable one.

2.6.2.2 Non-CIISE Studies on RFID in RL

The other prior non-CIISE simulation-oriented work which has been published falls mainly into three broad categories: Maintenance, Repair and Overhaul (MRO) applications. Of the work published in this field much emphasis has been placed on aircraft and aero-engine MRO applications: firstly, Ramudhin, Paquet, Artiba, Dupré, Vavaro and Thomson [34] – research not specifically case study based; secondly, Luo, Liu, Aw, Ng and Zhang [35] – research not case study based; and thirdly, Wei He, Chi Xu, Yintai Ao, Xuejian Xiao, Eng Wah Lee, Eng Leong Tan [36] focused on middleware, was not industrially validated, and proposed an RFID hand-held system for the track and trace of components in an aerospace MRO environment. The work of Harun, Cheng and Wibbelman [37] was case study validated and has analyzed the use of RFID in the FL manufacturing context of the manufacture of aircraft component parts, specifically parts made from composite materials. The latter work concluded that, at a practical level, technical challenges remain associated with the use of tags on parts made from composite materials and the robustness of tags to survive the elevated temperatures to which parts are exposed during many part manufacturing processes (particularly in the case of composite parts). Here again the current study aims to address this challenge: specifically in the empirical aspect of the work mentioned previously in Section 1.2, the results of which are presented in Chapter 6.

Ramudhin *et al.* [34] proposed a generic framework to guide the design and selection of an RFID-based system to control the MRO activities of an aircraft engine manufacturer. The work identifies that there a 5 key issues that must be resolved for the efficient design and functioning of an RFID system in such a job shop application.

1. Optimal selection of tags and readers and their location;
2. Tag data information protocol (defining which information is to be logged, which is to be updateable/secure)
3. Middleware design
4. Data warehousing strategy
5. Integration of the system into the over-arching business process.

These issues will be discussed further in Chapter 5.

Jimenez *et al.* [38 & 39] have examined, using simulation approaches, the potential impact of RFID technology on aircraft, specifically helicopter, MRO operations. The work identifies the potential areas in which RFID could have a process improvement impact as being:

1. Elimination of paper records
2. Logistical improvements
3. Maintenance process improvements
4. Tool management
5. Configuration management
6. Maintenance planning

The majority of these aspects are also areas of potential improvement in an end-of-service-life helicopter upgrade program scenario. No clear picture emerges from the work of Jimenez *et al.* as to how comprehensive the RFID tagging of the components is assumed to be for that study: it can be assumed that life-limited components are tagged, but is not clear to what extent mechanical/avionic-electrical components (i.e. serialized Line Replaceable Units, (LRUs)) are tagged, and if structural parts are considered at all. A clear picture of this is obviously required if a business case justification for RFID component tagging is to be defined. The work of the current study presented in this thesis will clearly define the extent to which various levels of RFID component tagging, based upon realistic implementation scenarios, can be practicably carried out and the resulting effects on process efficiency and business case.

Three very pertinent studies by the US Naval Postgraduate School from a specifically remanufacturing perspective are presented by Miertschen and Forrest [28], Ferrer and Dew [29], and Ferrer, Heath and

Dew [30]. The initial study [28] was carried out in 2004 and was an analysis of the outcomes from the Tobyhanna Army Depot's RFID pilot program and represented an actual RFID implementation in the context of an MRO operation for two large sophisticated items of avionics equipment: specifically a tropospheric scatter microwave radio terminal, fitted with a total of 30 RFID tags, and a ground theatre air control system radar fitted with a total of 75 RFID tags. This study concluded that there was a clear financial benefit in the use of RFID tracking as an asset management tool within the specified MRO operation: the pilot project indicated an "ROI of less than one year".

The second and third studies by the NPS in 2008 [29] and 2011 [30] reported the work by the NPS into a process simulation-based analysis into remanufacturing operations in a virtual remanufacturing shop. In contrast to the earlier Tobyhanna pilot program the simulation work did not indicate significant efficiency savings would be accrued from the use of an RFID RTLS system. Three reasons were postulated in that study as to why this could be the case:

1. The very modest gains in process efficiency indicated by the simulation model actually translate into significant financial savings during a real-life implementation;
2. The gains from RFID implementation in an actual remanufacturing environment are not due to material flow efficiency improvements, but are due to other 'spillover effects" such as increased focus on "overtime, scheduling, shrinkage, etc";
3. Other "housekeeping and reorganization efforts" required to implement RFID actually generated the observed process flow efficiency gains observed at Tobyhanna, not the effects of the RFID technology itself.

2.7 Return on Investment of RFID Technology

The three studies [28, 29 & 30] mentioned in the previous section have considered the ROI implications of RFID technology in an MRO/remanufacturing context through a combination of actual pilot implementation and process simulation studies. The pilot implementation described in [29] indicated the potential for significant savings from implementing RFID technology in the remanufacturing operation, although as was highlighted previously it is not clear from the NPS studies that the savings are necessarily exclusively attributable to the effect of the RFID technology alone.

The research work of Űstűndağ, Baysan and Çevikcan [40] is also relevant in assessing the business justification (ROI) for RFID technology: that work carried out a simulation-based analysis of the cost-benefit analysis of re-useable RFID tags. The conclusion of that work was that the results were dependent upon the number and quality of the tags employed. Chapter 5 of this report will address this aspect directly in the context of the helicopter upgrade program.

2.8 Definition of the Research Gaps

2.8.1 Conclusion from the Literature Review

One of the conclusions which can clearly be drawn from the foregoing literature survey is that RL as a field of study is one of growing importance and that its relevance to strategies and methodologies in the field of environmental sustainability within the aviation domain is expected to increase in the coming years as a result of its contribution in greening of supply chains, the focus on responsible use of the planet's natural resources and the need for the aviation industry as a whole to conform to the sustainability norms being set by other more proactive sectors of industry.

In the aerospace domain studies indicate that there is a need to consider RL processes in a way that has not been addressed to date: this is particularly true for fixed-wing aircraft for the reasons described in Section 2.2. In the case of the helicopter domain the factors affecting the average in-service life of vehicles is not the same as fixed-wing aircraft and for companies with very large existing fielded helicopter fleets (such as Bell Helicopter) there is a definite imperative. As identified by the work of Rogers & Tibben-Limke [10] and Kotler [20] in Section 2.2.3, prolonging the useful service life of these vehicles in order maintains a lucrative revenue stream from them for as long as possible and prevents market penetration by competitors' products. As a result Bell Helicopter has embarked upon a significant product upgrade of its legacy Model 206L-1 and L-3 aircraft with a view to dramatically extending their service lives by radically adapting them to meet the more demanding contemporary requirements of the operators that currently use them. Such an upgrade program requires a very invasive teardown and remanufacturing of the product to create the more up-to-date, and more capable, Model 206L-4 variant. The extent of the teardown and remanufacturing process required to upgrade the product is inherently a significant RL process, not just a simply an in-service product modification. The nature of the teardown aspects of the upgrade process fits very well with the definition of RL established previously in Section 2.2.1. Consequently CIISE and BHTCL agreed that this research work will use the real-world example of Bell Helicopter's Model 206L-1/L-3 Upgrade Program as a very pertinent and practical case study for the evaluation of the effects of RFID technology in RL processes.

2.8.2 Overall Context of the Research

Bell Helicopter is in the process of implementing RFID technology in the new helicopter products it is currently developing and at least one of its competitors in the rotorcraft world, and one of its engine suppliers, has already implemented basic RFID component tagging systems on fielded products already in service. Despite these benchmarks Bell Helicopter does not have a fully developed strategy for the extent of the RFID embodiment it should be striving for on its products (i.e. the optimal number and nature of the potential RFID tagged components on a particular aircraft). The research work in this study will help provide answers to aspects of this problem. As a result, the work of this research will help establish, using simulation approaches, what level of on-aircraft RFID implementation could be appropriate for Bell Helicopter's commercial products going forward and the study will use the case study of the Model 206L-1/L-3 Upgrade Program to help establish best practice.

An additional aspect of this work is that in order to create a successful solution for the RFID implementation described above its development needs to be guided in order to create a robust system, and this study will adopt the approach of a "Design for Six Sigma" (DFSS) methodology to define that system. The Six Sigma methodology requires, as one of its first steps, the establishment of a concise but nevertheless clear definition of the research problem: this definition is presented in the next section.

2.8.3 Definition of the Research Problem

The Six Sigma philosophy to problem solving is grounded in the accurate capture of customer requirements. Consequently the first step in any DFSS project is to establish the precise problem or opportunity statement and in the case of this current research project it is defined to be:

Problem/Opportunity Statement

> *The Reverse Logistics disassembly ("parting out") time and decision-making quality should be improved for end- of-service-life (EOL) commercial helicopters. Based upon feedback from*

> *approved Customer Support Facilities (CSFs) these factors affect the cost (business case) for the recycling/reuse(upgrade)/disposal of EOL aircraft.*

Having established the problem to be addressed in these terms we have already begun to establish the measurable "high level" needs of the process under scrutiny: in this case the "time", "decision making quality" and "cost" or "opportunity" to be leveraged the DFSS approach. Typically the next step is to define a project objective which will address this requirement. Logically this objective must be in line with that set out in Section 1.2 ("Problem Statement and Research Objectives/Approach"). Based upon the original generic research proposal a pertinent project objective is defined as:

Preliminary Problem Formulation

> *Develop a representative modelling framework of the EOL aircraft disassembly process to permit the ROI of alternative enabling reverse logistics technologies to be evaluated.*

Having established the project objective in these terms, the next step in DFSS is to frame this problem statement within workable project boundaries for the project. Based upon this the project objective can be more precisely re-stated as follows:

Precise Research Problem Formulation

> *Develop a representative modelling framework using discrete-event simulation modelling techniques of the EOL aircraft disassembly process to permit the ROI of alternative enabling RFID reverse logistics technologies to be evaluated.*

The project definition statement will be the basis on which the DFSS method can be applied to develop a workable solution which will satisfy the quantifiable needs of the customers. The next Chapter will describe the Six Sigma method in more detail, explaining the generic gated (or phased) process nature of its approach prior to discussing its specific application to the specific case study of the Model 206L-1/L-3 Upgrade program in Chapter 5.

CHAPTER 3 - PROPOSED SOLUTION APPROACH (USING THE DESIGN FOR SIX SIGMA METHODOLOGY)

3.1 Overview of the DFSS Methodology

As was mentioned previously in Section 1.2, given that this study is conceiving an innovative framework (or system) for the use of RFID technology in the context of the reverse logistics and remanufacturing of end-of-service-life helicopters, there is a need for a process for the development, assessment and validation of the conceived system. In order to facilitate the creation of such a process, which does not exist currently at Bell Helicopter, a "Design for Six Sigma" (DFSS) approach will be adopted in order to systematically gather the requirements, design a feasible system, enable the system to be piloted (in this case via simulation), and the results validated. Although the DFSS methodology is well established and documented there are company-to-company variations in the way in which it is implemented. The approach adopted here is based upon that used in Textron's (Bell Helicopter's parent company) Design for Six Sigma method which is a 7-stage process which can be summarized as comprising the following steps:

1. Requirements Definition: defining the customer requirements for the product or process and assessing the readiness of the technology or technologies which could drive the solution to fulfill these requirements.
2. Conceptual Design and Feasibility: generating the functional requirements for the process or product design (i.e. the things that the process must do, or make happen), generating the potential design solution concepts and undertaking a preliminary assessment of these solutions.
3. Preliminary Design: mapping the functional requirements to the potential design parameters, and assessing the "Design for X" (DF_x) aspects of that preliminary design.

4. Detail Design: consider whether a simulation or "Design of Experiments" (DoE) approach would be viable/preferred in the design's maturation, create the transfer function and map the design parameters to the process variables.
5. Pilot/Prototype: construct a pilot or prototype (model or simulation) of the new process or product and test it successfully.
6. Product and Process Validation: involves the successful implementation of the design solution in a truly representative production (or service) environment and assessing potential error-proofing opportunities.
7. Transitioning to Production/Service Implementation: formally launching the newly designed product or service into the production (fielded service) environment.

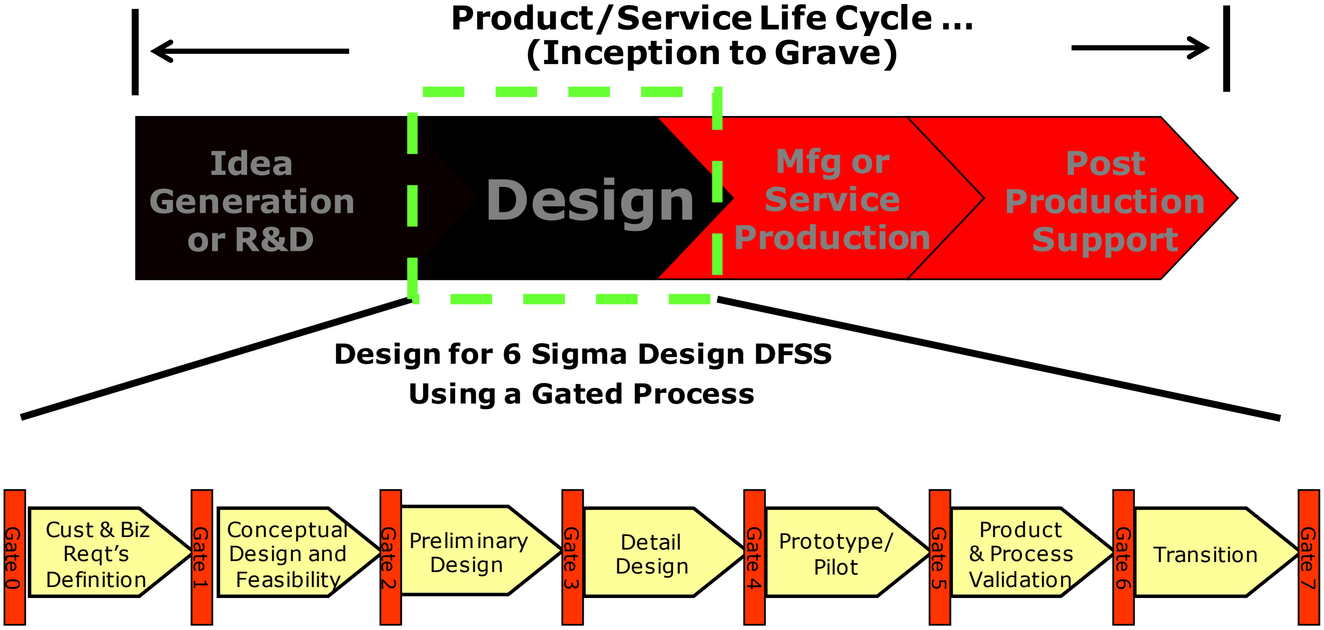


Figure 3-1: DFSS Process (Image Courtesy of Bell Helicopter)

The intent of the entire 7-step DFSS method described above is to develop a fully productionized (i.e. implemented) system solution, however for the purposes of this research project only the first five phases of the DFSS methodology are applicable since no attempt will be made under the current research study presented in this thesis to implement the design solution in a truly production environment (DFSS Phase 6), and certainly not to formally launch the solution into production (DFSS Phase 7). Hence the ongoing purpose of this research will focus on developing the path from the basic requirements definition (DFSS Phase 1) through to the prototyping of the solution (DFSS Phase 5): in this case the running of the simulation model, the analysis of the results and evaluation of the prototype RFID label technology described in Section 1.2. This is consistent with the "Problem Statement and Research Objectives/Approach" described in Section 1.2 and the "Definition of the Research Problem" defined in Section 3.3.

3.2 DFSS Phase 1 - Requirements Definition

Given the context and boundaries of the research problem defined previously in Chapter 3, the DFSS approach mandates establishing a clear set of requirements for the system to be defined by this study. In the previous chapter (Section 3.3) it was highlighted that every Six Sigma project must define the opportunity or problem to be addressed. In this case the opportunity has been defined as:

- ***The RL disassembly ("parting out") time and decision-making quality should be improved for end- of-service-life (EOL) commercial helicopters. Based upon feedback from approved Customer Support Facilities (CSFs) these factors affect the cost (business case) for the recycling/reuse(upgrade)/disposal of EOL aircraft.***

Again from Section 3.3 the associated project objective based upon the above statement is as follows:

> ***Develop a representative modelling framework using discrete-event simulation modelling techniques of the EOL aircraft disassembly process to permit the ROI of alternative enabling RFID reverse logistics technologies to be evaluated.***

In-scope/Out-of-Scope

Having established the problem objective in these terms, the next step in DFSS is to frame this project objective within workable project boundaries. The Six Sigma tool which facilitates this is the "In Frame / Out of Frame" (IF/OF) pictorial tool, and the results of its application to this project are shown in Figure 3-2.

Based upon the elaborated project objective subsequent discussion within BHTCL, and between BHTCL and CIISE, considered what the appropriate boundaries of the project should be, using the IF/OF tool. The principle involves segregating those aspects of the project based upon the objective previously defined which are regarded as being within the achievable scope of the project's work. These aspects were identified to be, for the in-scope items:

1. Reverse logistics (supply chain) RFID use cases
2. Comparative assessment of scenarios
3. Commercial helicopter platforms
4. New aircraft development platforms
5. ROI modelling / simulation
6. RFID tagging of lifed components
7. RFID tagging of serialized Line Replaceable Units (LRUs) (mechanical and electrical/avionic)

8. RFID tagging of system components (mechanical & electrical)
9. RFID tagging of structural components
10. Benchmarking other industries' approaches
11. Laboratory evaluation of RFID labels in harsh environments

Similarly the aspects defined as being firmly out of scope of the project are:

1. Military aircraft platforms
2. Forward logistics (supply chain) RFID use cases
3. Legacy (in-service) aircraft fleet
4. Highly-Accelerated Life Testing (HALT) for the tag-to-component long-term bonding aspects of implementing RFID technology in service

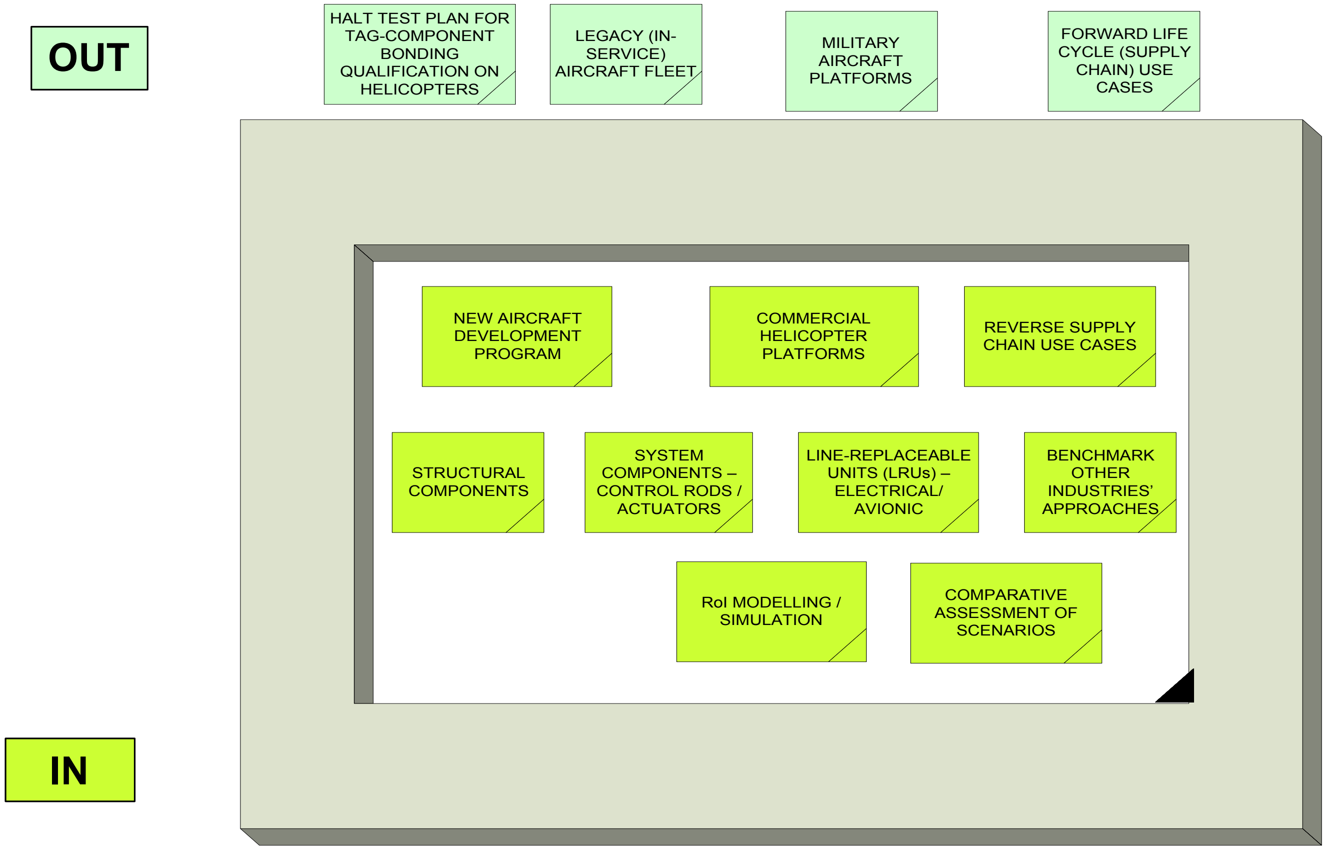


Figure 3-2: DFSS Process In-frame/Out-of-frame Tool Results

Having used this tool and established this clarity of scope, a fuller project definition can now be defined, together with a clearer idea of the desired project outcomes, expressed as a "Project Charter":

- *This project will be successful when:*
  - *"It develops a modelling framework for the use of RFID technology in the RL network of aircraft components (specifically commercial helicopters). This modelling framework will have the following attributes:*
    - » *It will model an actual RL process at an actual operator ("Operator A") as a case study (using the actual measured data – process steps/task times/resources). [This case study is currently not time/resource constrained.]*

    - *It will use simulation to assess the impact of different levels of RFID implementation on this process based upon practical, technologically achievable, four RFID implementation scenarios*
        - *Limited Lifed-component tagging*
        - *Serialized LRU component tagging (being implemented by Bell Helicopter on a current development program)*
        - *Structural (metallic and composite) component tagging (under development)*
        - *Progressive combinations of the above options*
- *This modelling framework will also have the following attributes:*
    - *Based upon available and representative cost data the business case for the various levels of RFID implementation will be calculated*
        - *It will provide an ROI model to assess the financial viability of each RFID scenario's technology solution business case*
- *The project has a secondary (empirical) aim of assessing the readability of label-type RFID tags for structural components in a harsh (industrial manufacturing) environment, using current tag material technology, as dictated by the four RFID implementation scenarios described previously*

It is against this DFSS "Project Charter" that the success or otherwise of this research project will be assessed at its conclusion. Naturally the project will also draw relevant conclusions and recommend appropriate next steps.

Defining the Key Process/System Requirements

Having established the comprehensive project definition in this way the next step in the DFSS process is to define the key requirements (high-level needs, HLNs) for the desired RFID modelling framework process. Based upon a knowledge of BHTCL's needs for the process, and after consultation ('sanity checking') with CIISE, a set of HLNs were established. These HLNs are set out below and require that the modelling framework must be:

- (Easy) Straightforward to implement and to use
- Representative of an actual RL process
- Gives accurate predictions (Basic process is verified as far as practicable)
- Adaptable (Scope for analyzing other scenarios in the future)
- Scenarios are realistic: the use cases are relevant to customer needs
- The assumed RFID technology works (Assumed RFID technology must be at a sufficiently mature Technical Readiness Level (TRL))

One of the defining characteristics of the DFSS approach to problem solving is the fact that it is metrics based: it is grounded in the philosophy of "that which cannot be measured cannot be managed". As such DFSS mandates that "Critical to Satisfaction" (CTS) metrics or indicators must be established for each of the HLNs defined above. These CTSs will represent the measurable metrics (the process "Y's) that will drive process performance. Consequently consideration was given to what the relevant CTSs could be associated/attributed to the HLNs. Figure 3-3 shows the CTSs associated with each of the HLNs.

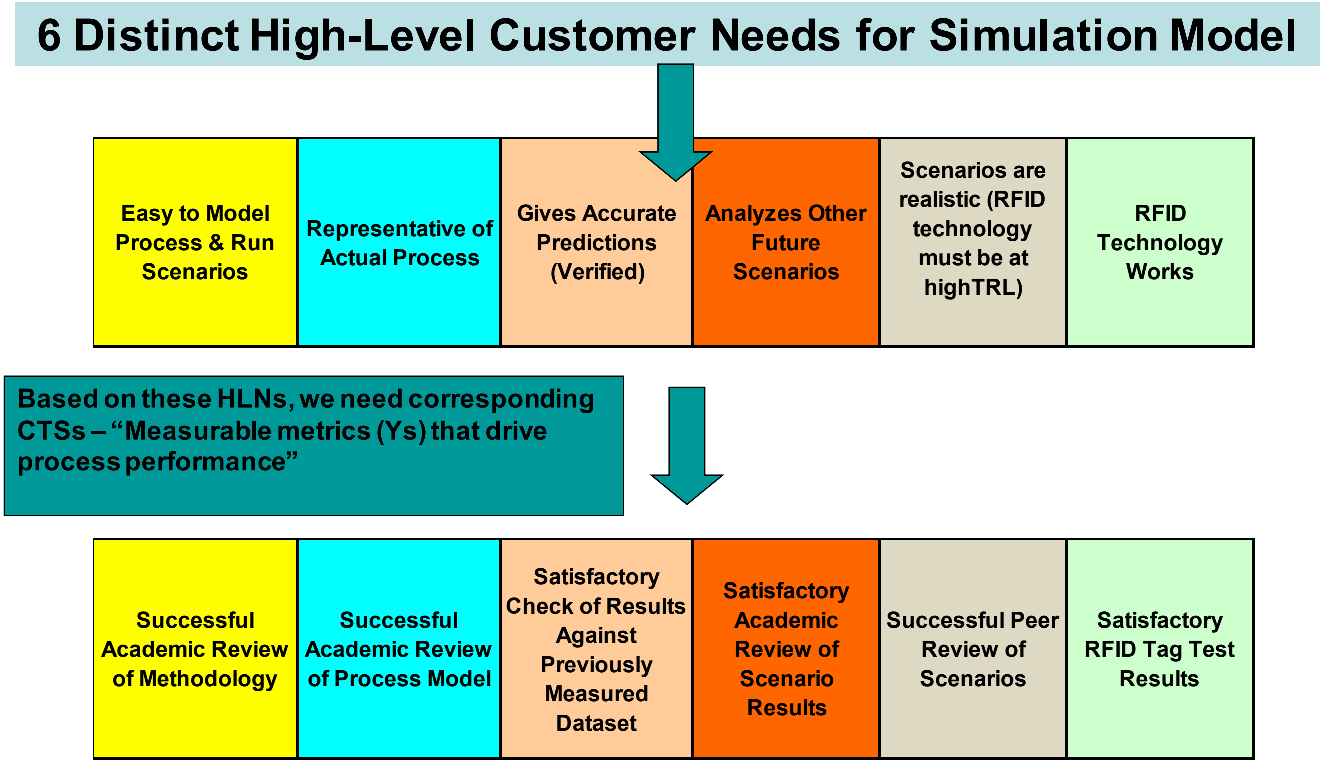


Figure 3-3: DFSS Process: Link Between HLNs and CTSs

3.3 DFSS Phase 2 - Conceptual Design and Feasibility

Under the DFSS approach, having satisfactorily defined the HLNs (requirements) and their associated metrics, or CTSs (i.e. the measurable/verifiable way in which it can be established the HLNs have been satisfied) the next step is the generation of conceptual options (or potential solutions) for the modelling framework. Naturally, implicit in this activity is the need to establish the Functional Requirements (FRs) for the process: the FRs are the things which the process must do or make happen in order to drive process performance. As a result each of the HLNs was considered in turn and one (or more) functional requirements were developed which directly addressed these associated HLNs: in DFSS there can be more FRs than HLNs since an individual

HLN may generate more than one FR. The result of the process developed the following list of FRs (the associated HLN has been identified in brackets in each case).

This modelling framework (process) must make the following happen in order to achieve customer satisfaction:

- *The Functional Requirements (defined as an 'action verb plus noun'):*
  - *Use commonly used simulation technique (HLN #1)*
  - *Model the helicopter disassembly RL process (HLN #2)*
  - *Count the touch time activities (HLN #3)*
  - *Count the non-touch time activities (HLN #3)*
  - *Validate the process (HLN #3)*
  - *Assess different RFID implementation scenarios (HLN #4)*
  - *Consider realistic (technically achievable) RFID implementation scenarios (HLN #5)*
  - *Provide RFID solutions that work (HLN #6) (RFID technology must be at a sufficiently highTRL)*

The outcomes of this analysis are presented schematically in Figure 3-4. The generation of valid FRs is the key to the next step in the DFSS process: the successful generation of an array of design <u>solution</u> options. The tool which is used for this step is the "Morphological Matrix": essentially the matrix is a means to show the process's functions and the corresponding "design parameters" (i.e. the solutions which address the FRs). Using this tool allows the DFSS analyst to create design solutions for each of the FRs defined previously. In some instances only one design solution may present itself for a particular FR. In other instances more potential solutions may be possible to satisfy a specific FR (in the process under consideration up to 5 were possible in some cases).

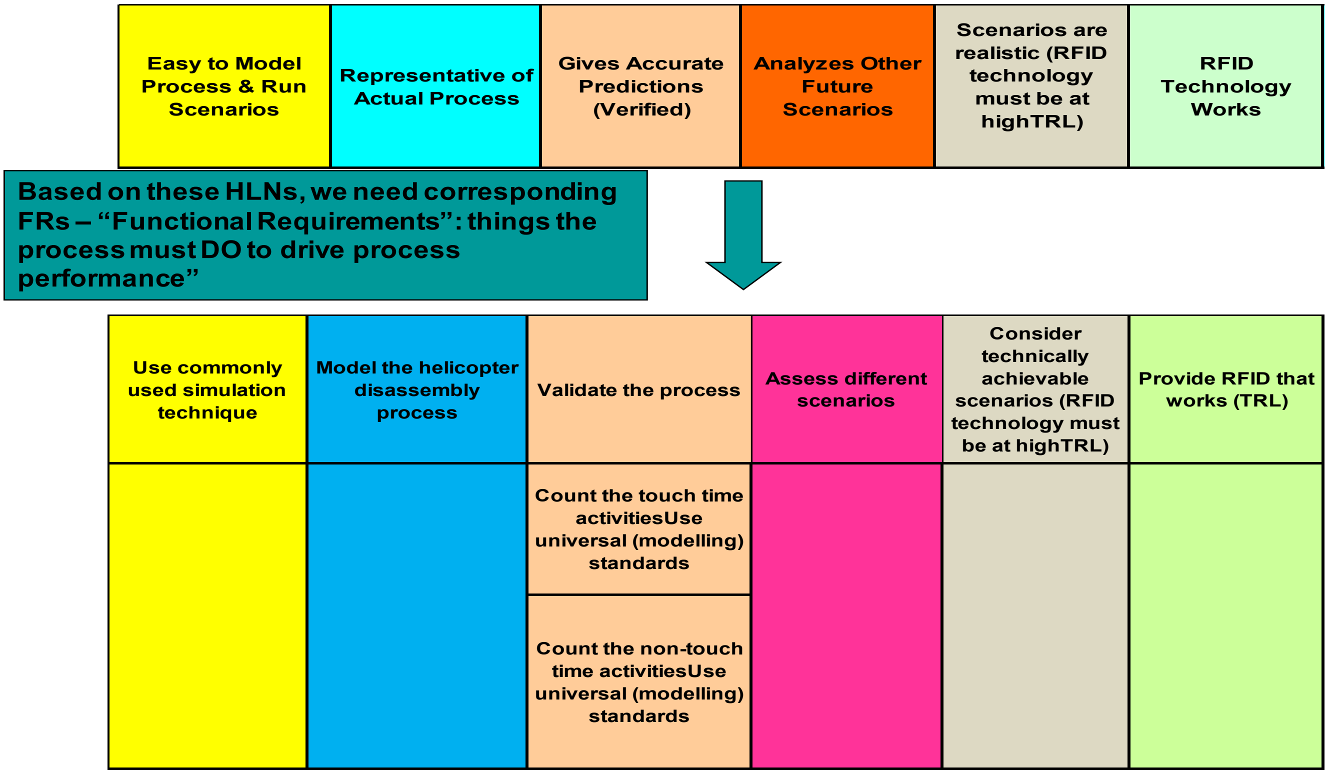
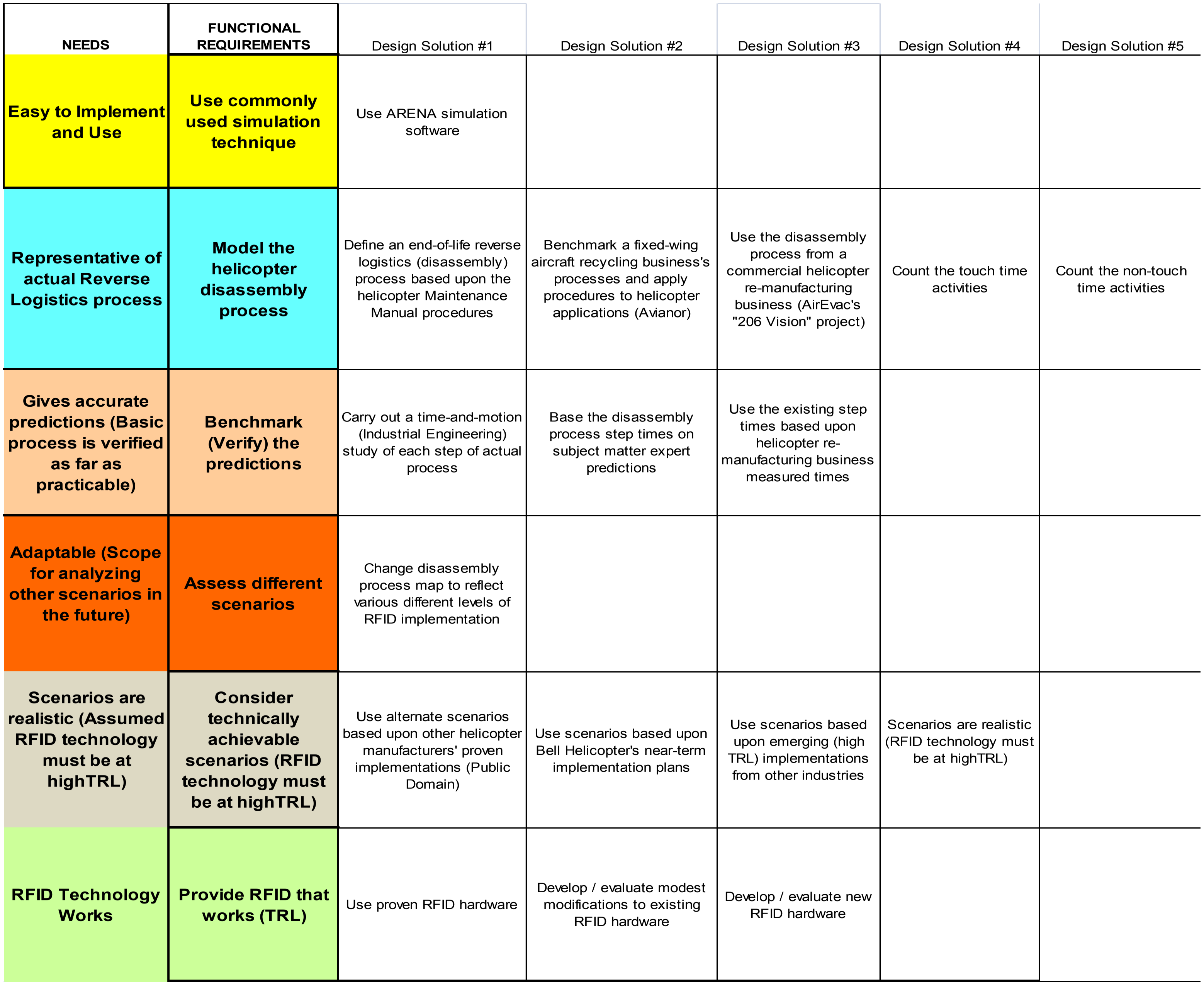


Figure 3-4: DFSS Process: Link Between the HLNs and the Process FRs

In the DFSS process the next step is the generation of the design solutions based upon the knowledge of the FRs. No constraints are placed on the practicality/feasibility of the solutions generated at this stage: the objective is to allow "out of the box" possibilities, which can subsequently be refined.

In DFSS the tool which is used to develop/record these brain-stormed design solutions is the "morphological matrix". Figure 3-5 shows the fully developed morphological matrix which was derived for this specific process.



NEEDS	FUNCTIONAL REQUIREMENTS	Design Solution #1	Design Solution #2	Design Solution #3	Design Solution #4	Design Solution #5
Easy to Implement and Use	**Use commonly used simulation technique**	Use ARENA simulation software				
Representative of actual Reverse Logistics process	**Model the helicopter disassembly process**	Define an end-of-life reverse logistics (disassembly) process based upon the helicopter Maintenance Manual procedures	Benchmark a fixed-wing aircraft recycling business's processes and apply procedures to helicopter applications (Avianor)	Use the disassembly process from a commercial helicopter re-manufacturing business (AirEvac's "206 Vision" project)	Count the touch time activities	Count the non-touch time activities
Gives accurate predictions (Basic process is verified as far as practicable)	**Benchmark (Verify) the predictions**	Carry out a time-and-motion (Industrial Engineering) study of each step of actual process	Base the disassembly process step times on subject matter expert predictions	Use the existing step times based upon helicopter re-manufacturing business measured times		
Adaptable (Scope for analyzing other scenarios in the future)	**Assess different scenarios**	Change disassembly process map to reflect various different levels of RFID implementation				
Scenarios are realistic (Assumed RFID technology must be at highTRL)	**Consider technically achievable scenarios (RFID technology must be at highTRL)**	Use alternate scenarios based upon other helicopter manufacturers' proven implementations (Public Domain)	Use scenarios based upon Bell Helicopter's near-term implementation plans	Use scenarios based upon emerging (high TRL) implementations from other industries	Scenarios are realistic (RFID technology must be at highTRL)	
RFID Technology Works	**Provide RFID that works (TRL)**	Use proven RFID hardware	Develop / evaluate modest modifications to existing RFID hardware	Develop / evaluate new RFID hardware		

Figure 3-5: DFSS Process: Basic Morphological Matrix

The design solutions were then colour-coded to identify (categorize) the solutions into the following groups:

Green: Definite candidate go-forward solution

Yellow: Solution requires further near-term work/refinement before inclusion

Blue: Potential solution for integration at a later date (longer term, beyond this current study)

Red: Not a viable solution

The result of this categorization process is shown in Figure 3-6. Based upon this it was then possible to identify the solution or solutions which are truly regarded as being feasible options against the previously established FRs. The morphological matrix was then be used to identify if there is any way in which the viable design solutions (the individual boxes in the rows of the table) can be combined or "hybridized" to create a more comprehensive (combined, but nevertheless viable) solution which is an enhancement over any of the previously conceived individual design solutions. In fact it was observed that some of the design solutions could indeed be combined and this option is shown in Figure 3-6 in the final (right-hand) column entitled "Hybrid Solution".

NEEDS	FUNCTIONAL REQUIREMENTS	Datum Design	Option #1	Option #2	Option #3	Option #4		Best (Hybrid ?) Option
Easy to Implement and Use	**Use commonly used simulation technique**	Use ARENA simulation software						Use ARENA simulation software
Representative of actual Reverse Logistics process	**Model the helicopter disassembly process**	Define an end-of-life reverse logistics (disassembly) process based upon the helicopter Maintenance Manual procedures	Benchmark a fixed-wing aircraft recycling business's processes and apply procedures to helicopter applications (Avianor)	Use the disassembly process from a commercial helicopter re-manufacturing business (AirEvac's "206 Vision" project)	Count the touch time activities	Count the non-touch time activities		Use the disassembly process from a commercial helicopter re-manufacturing business AND include touch-time and non-touch-time activities
Gives accurate predictions (Basic process is verified as far as practicable)	**Benchmark (Verify) the predictions**	Carry out a time-and-motion (Industrial Engineering) study of each step of actual process	Base the disassembly process step times on subject matter expert predictions	Use the existing step times based upon helicopter re-manufacturing business measured times				Use the existing step times based upon helicopter re-manufacturing business measured times AND subject matter expert predictions
Adaptable (Scope for analyzing other scenarios in the future)	**Assess different scenarios**	Change disassembly process map to reflect various different levels of RFID implementation						Change disassembly process map to reflect various different levels of RFID implementation
Scenarios are realistic (Assumed RFID technology must be at highTRL)	**Consider technically achievable scenarios (RFID technology must be at highTRL)**	Use alternate scenarios based upon other helicopter manufacturers' proven implementations (Public Domain)	Use scenarios based upon Bell Helicopter's near-term implementation plans	Use scenarios based upon emerging (high TRL) implementations from other industries	Scenarios are realistic (RFID technology must be at highTRL)			Use alternate scenarios based upon other helicopter manufacturers' proven implementations (Public Domain) AND Bell's near-term plans AND non-aerospace implementationsAND use realistic (High TRL) scenarios
RFID Technology Works	**Provide RFID that works (TRL)**	Use proven RFID hardware	Develop / evaluate modest modifications to existing RFID hardware	Develop / evaluate new RFID hardware				Use proven RFID hardware AND develop / evaluate modest modifications to existing RFID hardware

Figure 3-6: DFSS Process: “Categorized” Morphological Matrix

So, at the conclusion of this phase of the DFSS process the optimal design solution is one which:

- Arena simulation software will be used to model the disassembly process from a commercial helicopter remanufacturing operation: touch time and non-touch time activities will be considered and the input times used will be based upon measured process times and estimates provided by subject matter experts. The modelling framework will change the disassembly process to reflect various different RFID implementation scenarios: these scenarios will be based upon the known (public domain) implementation scenarios of other helicopter manufacturers, Bell Helicopter's own (public domain) near-term plans, other non-aerospace implementations (if appropriate). The framework will be based upon current RFID technology and/or RFID hardware developed and proven to work (to an appropriate TRL level) during the course of this research study.

This constitutes a detailed specification for the work of this research study.

3.4 DFSS Phase 3 - Pre-Design

Having previously defined the optimal design solution approach, in the next phase of the DFSS method, the "pre-design phase", the objective is to link the functional requirements to the "design parameters". The latter are the input parameters, the process X's: the things which one must input into the design solution (i.e. the process) in order to produce the desired result. In other words, in 6-sigma terms, the pre-design phase defines process inputs which will enable the execution of the functional requirements. For the RFID framework solution under development the process X's (inputs) are considered to be:

1	Discrete event simulation software (ARENA)
2	Real-life RL case study (to model)
3	Real-life RL case study input data (task times)
4	Realistic RL RFID implementation scenarios (to model)
5	Representative RL RFID scenario input data (task times)
6	Design criteria for developed RFID technology (Physical Characteristics)
7	Design criteria for developed RFID technology (Geometry)
8	Design criteria for developed RFID technology (Performance)
9	Design criteria for developed RFID technology (Survivability)

Table 3-1: DFSS Process: Definition of Design Parameters (The Process "X's")

These are the items which will be fed into the RFID modeling framework in order to achieve the desired result.

3.5 Phase 4- Detail Design of the Solution

This phase of a DFSS project takes the design parameters derived in the previous Phase 3 and makes a determination as to whether a simulation or empirical (e.g. Design of Experiments) approach would be viable in the design's creation. Furthermore this DFSS phase must also clearly identify the relationship between the process inputs, the "design parameters" (or "X's") which were developed previously in Section 3.4 and the "process variables" (or "Y's"). These are shown graphically in Figure 3-7.

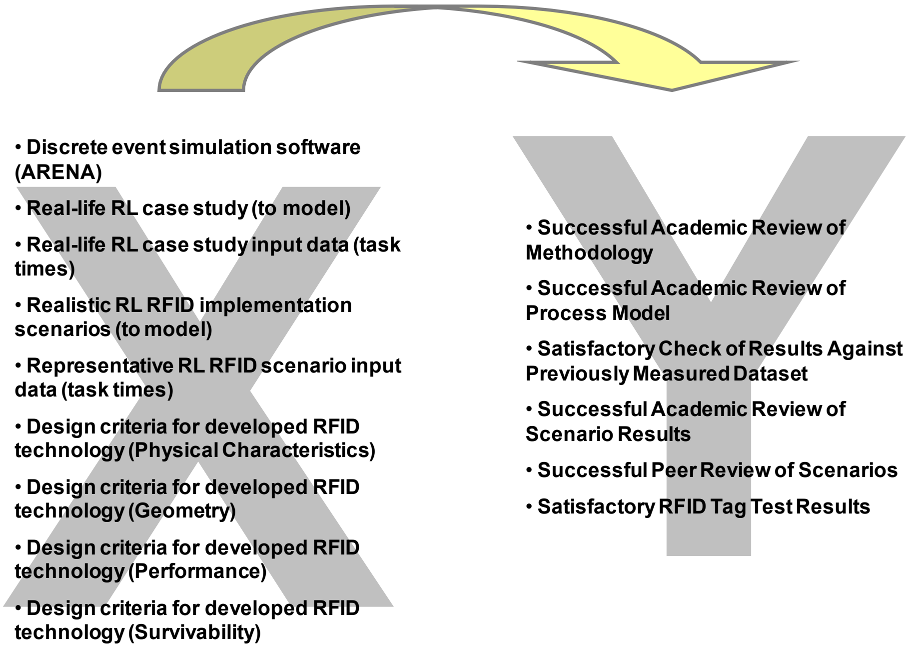


Figure 3-7: DFSS Process: Relationship Between the Process "Design Parameters" (or "X's") and the "Process Variables" (or "Y's").

As defined previously in Section 3.2 the design has two main deliverables:

1. The modelling framework for the use of RFID (including the ROI analysis)
2. The assessment of the label-type RFID tags

Clearly, for this project, these main deliverables each require a different detail design approach: the modelling framework requires a simulation approach and the RFID label assessment needs an empirical (test) approach. However it can be summarised here that the detailed design of the Arena simulation model involved process mapping the real-life disassembly process (as described in Sections 4.2 and 4.3); inputting the disassembly process step task times presented in Appendix One into the Arena model and defining the representative RFID scenarios to be assessed by the model (as described in Section 4.3.3).

The detailed design of the empirical (test) approach is involved defining the material (physical characteristics/construction) and geometry of the test coupons (see Section 5.3), the acceptable RFID label read-range performance (>3 ft) and the survivability criteria (Table 5-1),

Further elaboration of the detailed construction of the RFID simulation modelling framework and the design development of the prototype RFID labels are presented in Chapters 4 and 5 respectively.

3.6 DFSS Phase 5 - Pilot/Prototype of the Proposed Solution by Discrete Event Simulation

The previous section highlighted the way in which this research effort comprises both simulation work and experimental testing of hardware in order to pilot the RFID framework solution being proposed.
As mentioned in Section 3.1 the goal of this research is to pilot the proposed solution, draw conclusions and make recommendations based upon that pilot's results. Although all the phases of any DFSS project are linked the detail design of the proposed solution and its prototyping are particularly closely related, hence the results of the prototype running of the simulation model and the results of the label testing are also presented in Chapters 4 and 5 respectively.

In summary, in Chapter 4 the Arena simulation tool will be used to pilot the modelling framework for the use of RFID technology in RL, and as mentioned in Section 3.2 an actual case study situation will be used as the basis for this study. In Chapter 5 the secondary empirical (experimental) aim of this research project, described in the problem definition Section 3.2, has the aim of assessing the robustness of a label-type RFID tag for use on structural components. This robustness assessment has been undertaken as part of this project and has resulted in the development of this improved capability label-type tag.

The analysis and results presented in the next two chapters collectively represent the pilot/prototype of the proposed DFSS solution for this research study.

CHAPTER 4 – DISCRETE EVENT SIMULATION CASE STUDY

4.1 Introduction

For the purposes of this research project a real-life case study has been chosen as a basis for assessing the adoption of RFID technology in the RL of helicopters. The specific case study chosen is well-suited to this field of research and involves Bell Helicopter's current "Model 206L *LongRanger* Upgrade Program" [4]. In 2008 Bell Helicopter realized that, although it had a very significant fielded fleet of over 1000 of its very successful Model 206L-1 and 206L-3 single-engine helicopters in operation, some of which had been flying for more than 30 years, many of the customers using the aircraft were progressively demanding a higher level of aircraft performance than these platforms were capable of delivering. At that time, although the 206L-1 and 206L-3 were no longer in production, a new more powerful derivative of this helicopter, the Model 206L-4, was in production and provided a performance level which was in line with current market demands, but the customers were unwilling to retire their existing in-service Model 206L-1/L-3 helicopters and buy brand new 206L-4 aircraft. This unwillingness to purchase brand new aircraft was driven primarily by economic considerations:

- The lack of a satisfactory business case for retiring the existing aircraft and using the new 206L-4 variant, and
- The long manufacturing/delivery lead-time which would be involved in waiting for new production L-4 aircraft to become available from Bell Helicopter.

Moreover, Bell Helicopter could not ramp up production of the newer Model 206L-4 helicopter to match the potential demand even if the customers were prepared to retire their old models.

The business solution devised by Bell Helicopter to address this problem was to embark on a product upgrade program of the Model 206L-1/-3 models which would provide the increased performance, increased reliability and decreased operating cost of the newer Model 206L-4 helicopters by means of a 'remanufacturing' of the existing in-service helicopters. The L-1/L-3 upgrade process is shown schematically in Figure 4-1 "Upgrade Structure". The full upgrade process for the L-1/L-3 remanufactures an individual L-1 or L-3 aircraft to be functionally equivalent to a contemporary new production L-4 aircraft. Figure 4-2 shows the first successfully upgraded L-1 aircraft, i.e. an L-1$^+$ when upgraded (shown parked on the ground, 'unpainted'), at the completion of the remanufacturing process, and the second L-1 aircraft arriving to be upgraded (shown in flight) at the service centre.

This upgrade program is accomplished by means of an Upgrade Kit which Bell Helicopter has marketed and which certain of its appointed third-party Service Centres worldwide are authorized to perform.

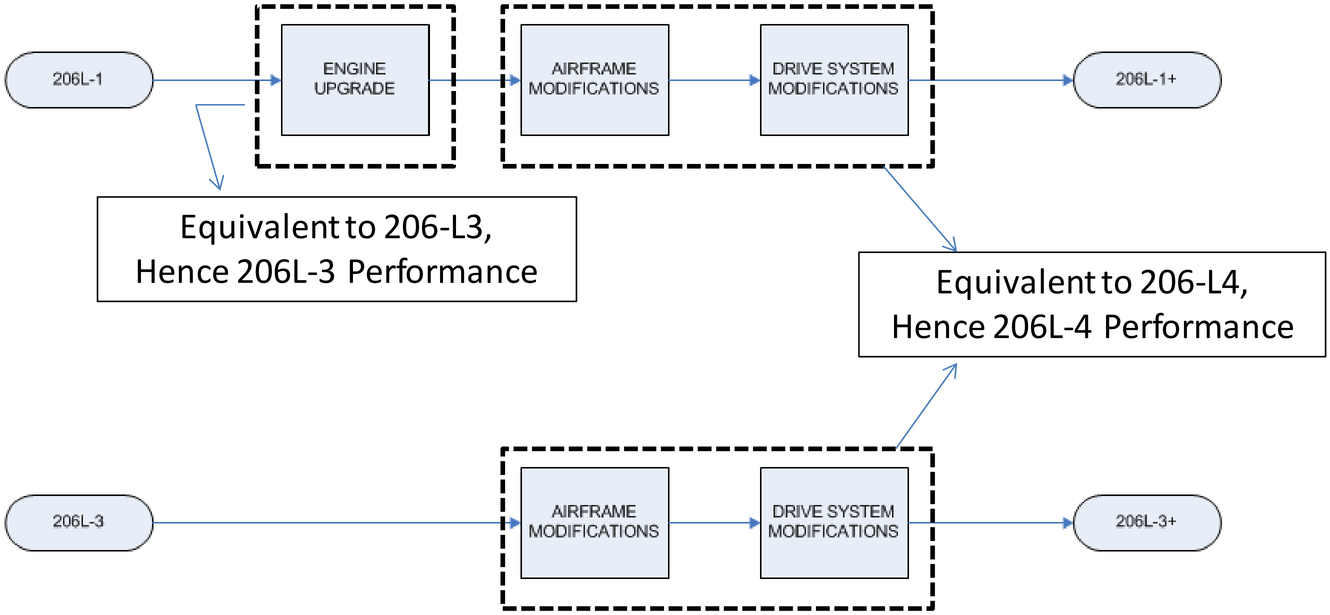


Figure 4-1 – Process Schematic for "Upgrade Structure" (Adapted from [4])

Figure 4-2 – Pre- and Post Upgrade Aircraft at Remanufacturing Facility

(Photo Courtesy of Bell Helicopter)

The remanufactured Model 206L-1 and 206L-3 helicopters which are upgraded during this project are designated as respectively Model 206L-1$^+$ and Model 206L-3$^+$ and each has the level of performance equivalent to the more contemporary Model 206L-4. The remanufactured helicopters comprise of (Figure 4-3):

- Upgraded dynamic components
- Strengthened airframe structure in key areas
- An increased transmission take-off power rating
- Upgraded engine
- A series of component reliability improvements

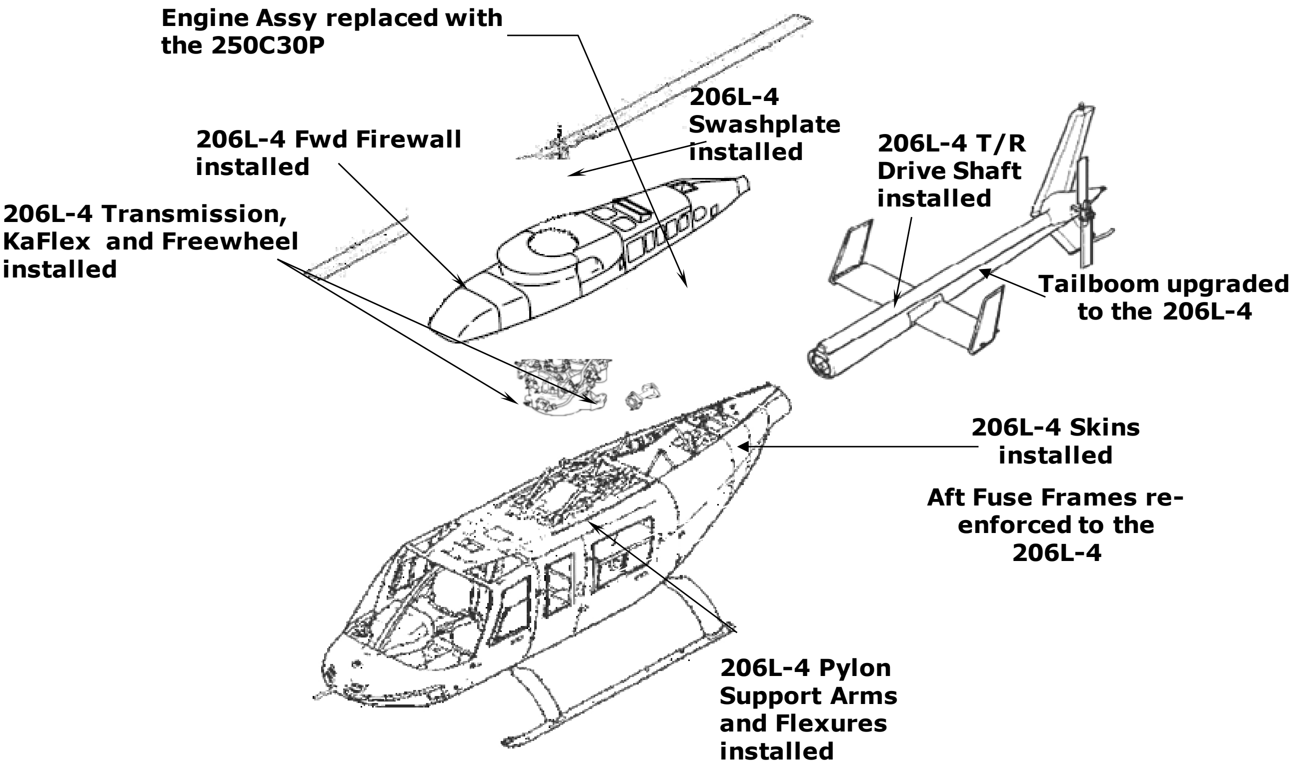


Figure 4-3 – Major System, Structural and Engine Modifications for Upgrade Kit

(For clarity, not all modifications shown)

As a result, vehicles fitted with this Upgrade Kit provide an aircraft with a higher gross weight capability, an increased take-off power, reduced operating costs and improved performance: all achieved through re-using a substantial proportion of the original L-1/L-3 vehicle. The upgrade (remanufacturing) program required to create this improved product involves a very substantial disassembly of the existing airframes: Figure 4-4 shows the condition of the helicopter airframe at the end of the component/system disassembly phase of that process (and prior to the reassembly phase).

Figure 4-4 – Condition of the Helicopter After Component/System/Structural Disassembly Phase

(Photo Courtesy of Bell Helicopter)

The upgrade is therefore inherently an RL process: in the case of either the L-1 or L-3 aircraft it involves the removal/rework of existing aircraft parts, and the replacement of some of the existing parts with new L-4 parts with increased capability/performance.

Using this true-to-life upgrade program as a simulation case study enables the research to pilot the modelling framework for the use of RFID technology in this RL process. The analysis of the results of this simulation study, using various levels of RFID implementation, will enable this study to make use of the conclusions drawn regarding this technology and make appropriate recommendations regarding its use. The next section provides background information regarding the real-life upgrade program.

4.2 The "Model 206L-1 Upgrade Program" Implemented at "Operator A"

The remanufacturing of the upgrade helicopters has been successfully carried out at an independent organization (known hereafter as "Operator A") which, as well as being itself a major operator of these aircraft for commercial EMS (Emergency Medical Service) applications (i.e. an air ambulance service provider), it is also an independent Bell-approved service centre. As an approved service centre it is therefore authorized by Bell Helicopter and by the FAA to carry out the necessary technical upgrade process in accordance with Bell Helicopter published technical documentation. The detailed planning for the RL disassembly process involved is well defined and is presented in the technical publications produced by Bell for this purpose. This detailed process planning has been used as the process steps in the analytical simulation modelling used in this research's case study. A very simplified schematic of this process is shown in Figure 4-5. Although the entire upgrade process involves the disassembly, rework and reassembly steps, only the disassembly (RL) aspects of the process will be analyzed as part of the simulation modelling (i.e. the parts of the process outside of the dashed box shown in Figure 4-5) in order to establish the impact of RFID technology on the remanufacturing process. Since over 40 upgraded aircraft have been produced at the "Operator A" Service Centre, reliable man-hour time estimates are available for each of the major disassembly process phases, and the specialist skill sets of the personnel involved and the precise number technicians required to carry out each phase are known. Based upon this, valuable and reliable boundary conditions are available for the purpose of creating a realistic model of this true-to-life case study. The specific process map for the aircraft disassembly process, shown in Figure 4-5, also shows the technical skill sets and the number of man-hours required for each major process step.

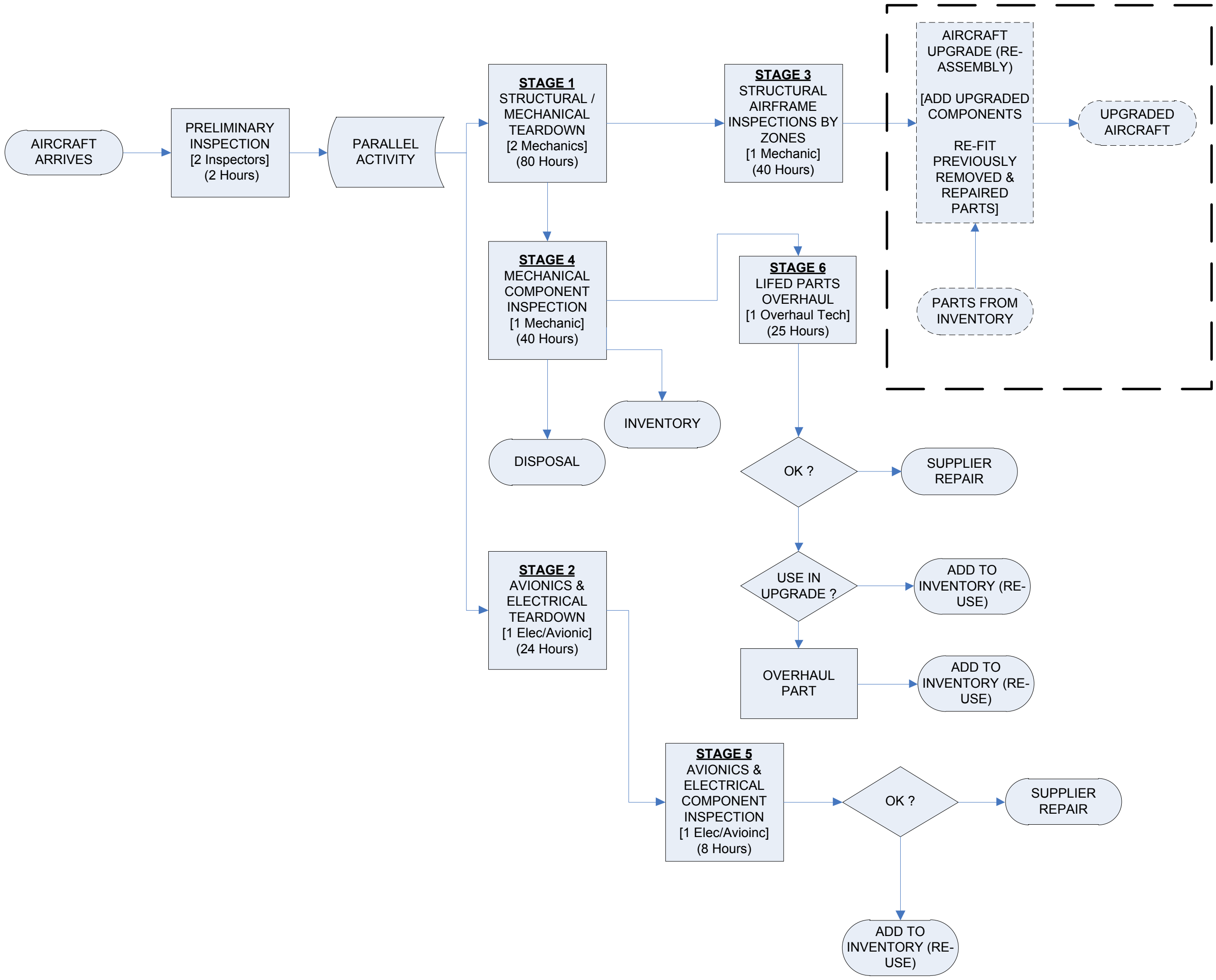


Figure 4-5: Process Map of the Upgrade Program

The detailed process planning steps within each major process step are shown in Appendix One. Since the individual task times were not measured by Operator A (the individual tasks number many hundreds for the entire disassembly process), they have been estimated by two of Bell Helicopter’s own Product Support specialists both of whom are licensed mechanics: one a subject matter expert in mechanical systems and structure and the other an expert in avionics and electrical systems. Both of these subject matter experts have first-hand knowledge of the Upgrade Program and both have spent a significant amount of time at the Operator A Service Centre witnessing the disassembly and remanufacturing process and therefore both individuals have "walked the process". Based upon their subject matter expertise individual task times were estimated for each task (for all the process "Stages" shown in Figure 4-5), with the constraints that the cumulative time for their task estimates ***had to agree with the known (measured) total for each major process phase provided by Operator A***. In each case the mechanical/structures subject matter expert's initial estimates did not match the measured totals, however, after a second 'iteration' (where appropriate adjustments were made by them to their initial individual estimates) the totals were found to agree either exactly, or in the worst case to within 1% of the measured value provided by Operator A. The same was true for the avionics/electrical subject matter expert. This level of agreement was considered quite acceptable for the purposes of this simulation study.

4.3 Modelling of the Upgrade Program Process

4.3.1 Basic Simulation Model Structure in Arena

The RL aspects of the Upgrade Program, as shown schematically in Figure 4-5, and as reflected in the actual detailed process planning steps' data (as shown in Appendix One), were input into the Arena discrete event simulation software. The top-level model is shown schematically in Figure 4-6.

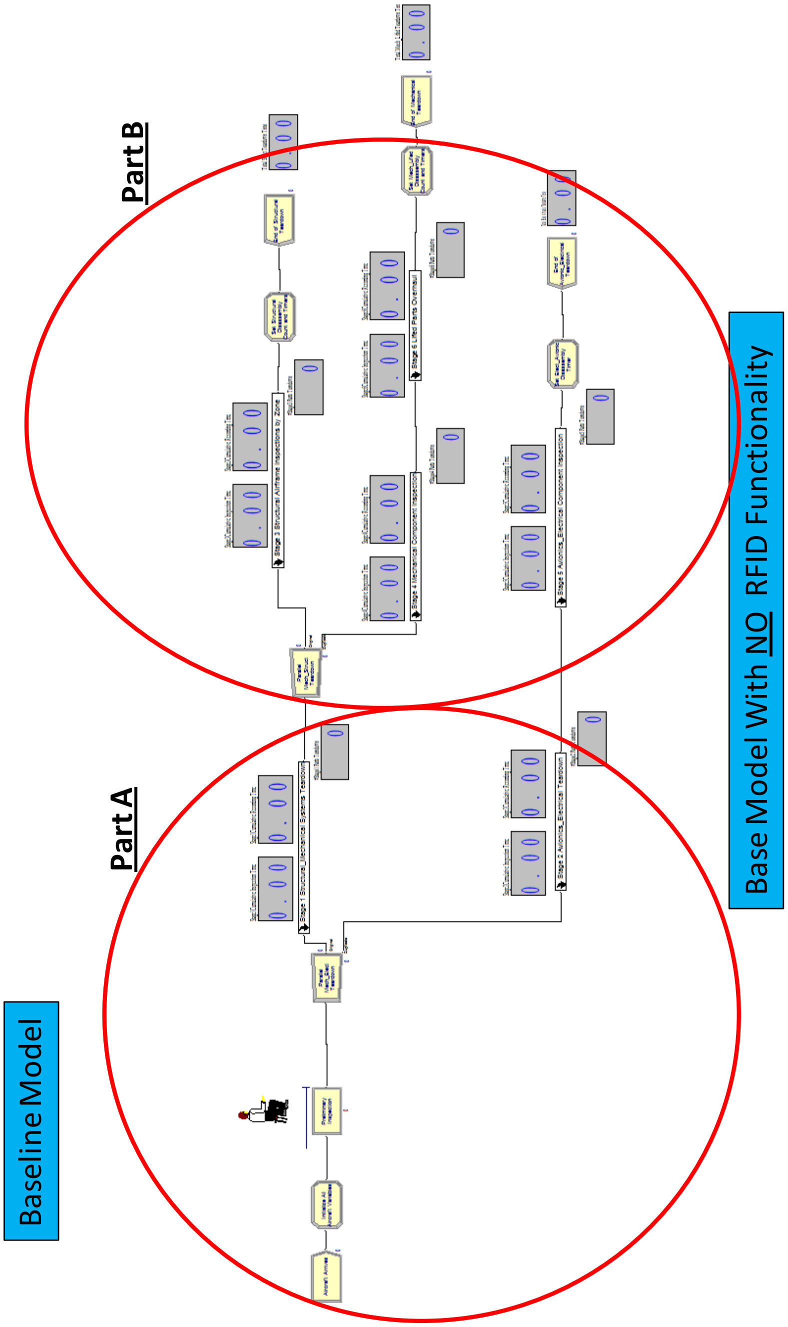


Figure 4-6: Top-level Simulation Model (Parts A & B)

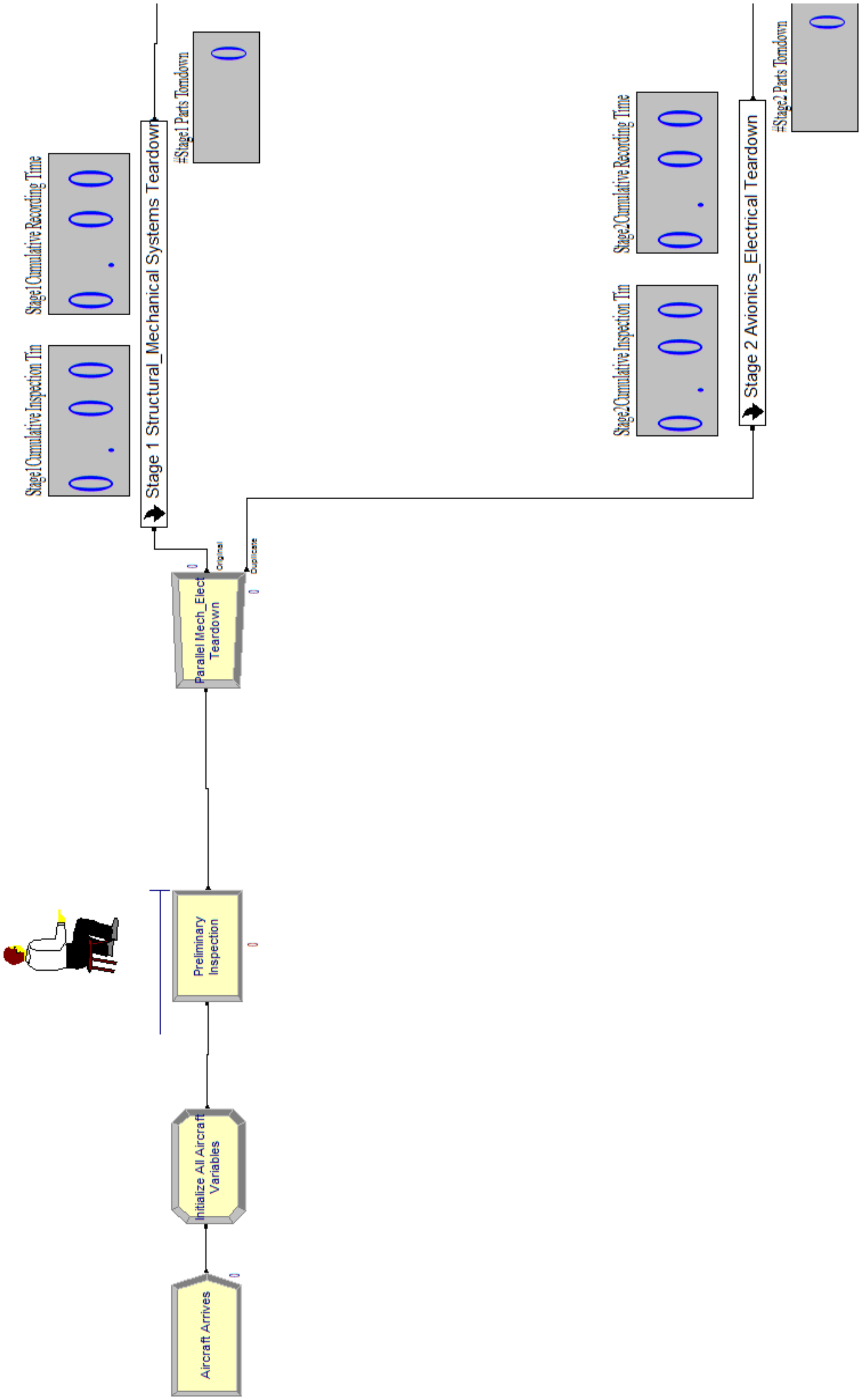


Figure 4-6a: Top-level Simulation Model (Part A)

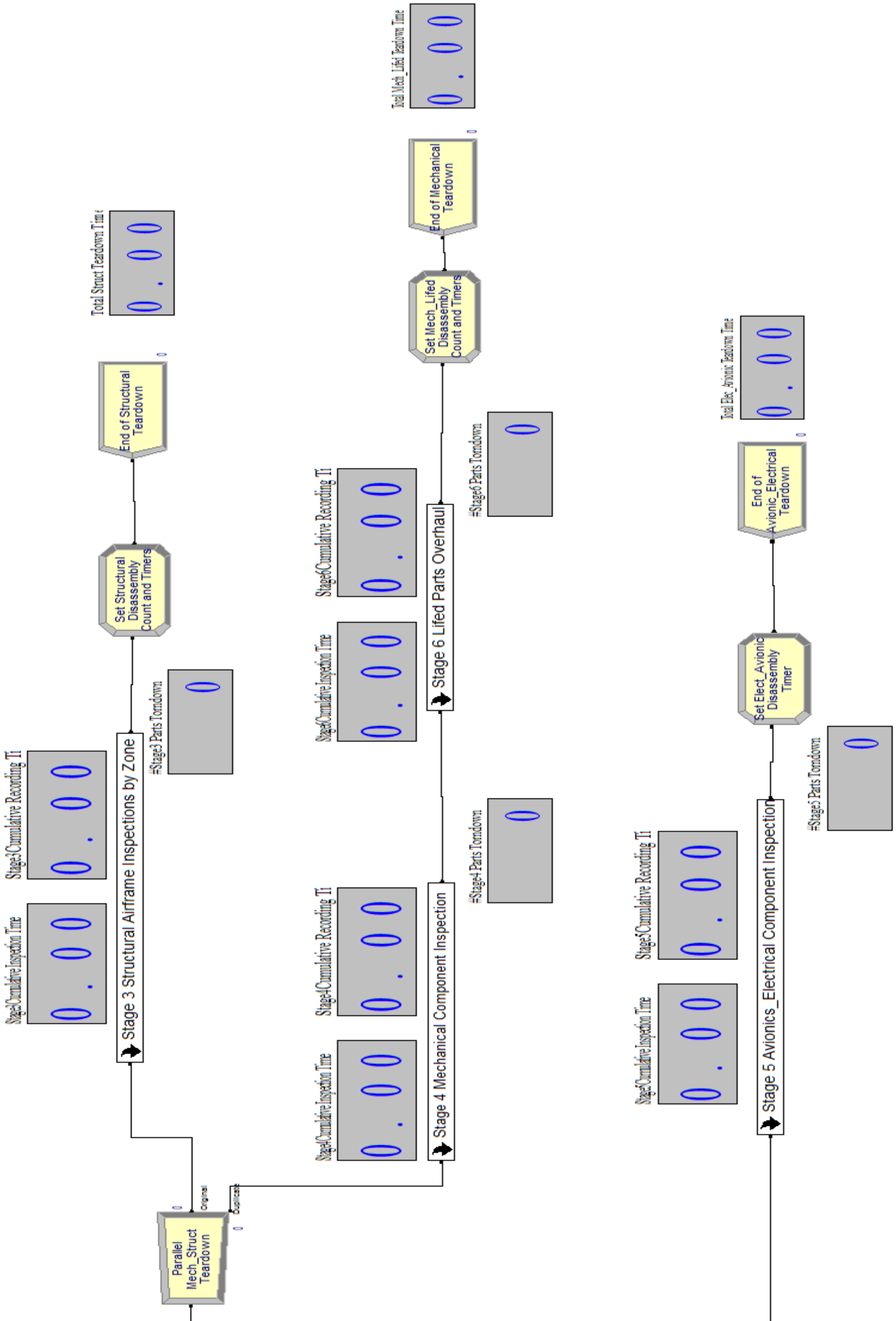


Figure 4-6b: Top-level Simulation Model (Part B)

As can be seen from this figure, the representation of the process in Arena has been modularized to reflect as accurately as possible the actual process flow chart shown in Figure 4-5: hence the sub-process blocks of the actual process (e.g. Stage 6: the stage/phase for dealing with “lifed parts”) are shown as discrete modular blocks in the Arena simulation. Figure 4-7 shows an example (taken from Stage 1- Structural/Mechanical Teardown) of the details that lie within these Arena modular blocks for the main process “Steps” (or Stages).

In each of these Arena blocks the logic of each Stage has been modeled as a “Do-loop” in order to mimic the repetitive removal/inspection and labelling/recording activities inherent in each step. Only Stage 6 (Overhaul of Lifed Parts) is slightly different in that it comprises only a repetitive analysis/recording activity of the previously disassembled lifed parts: there are no removal, inspection, or labelling activities involved in this phase during the actual real-life process.

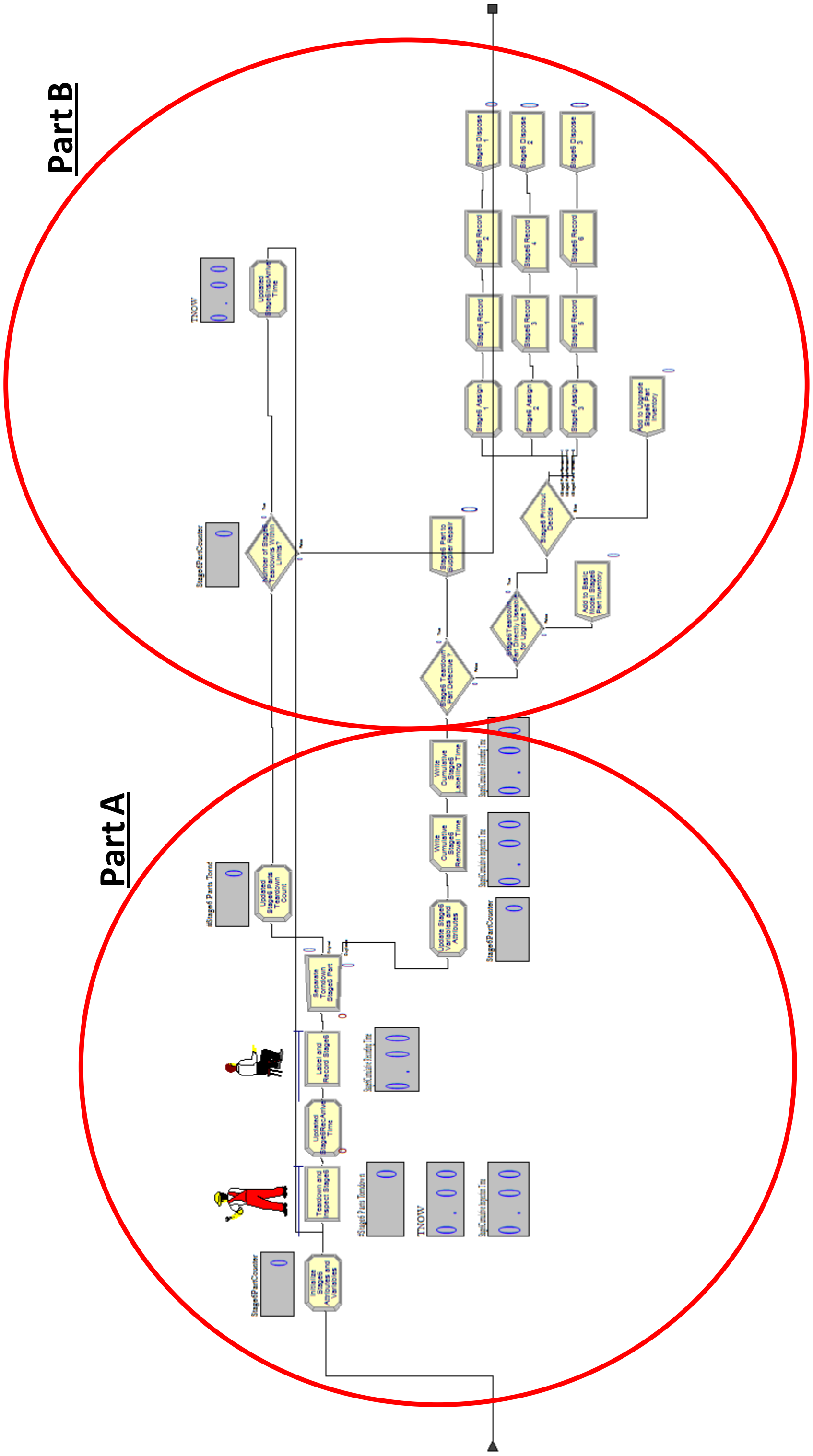


Figure 4-7: Example of Detail-level Simulation Modular Block (Parts A & B)

(Taken From Stage 1- Structural/Mechanical Teardown)

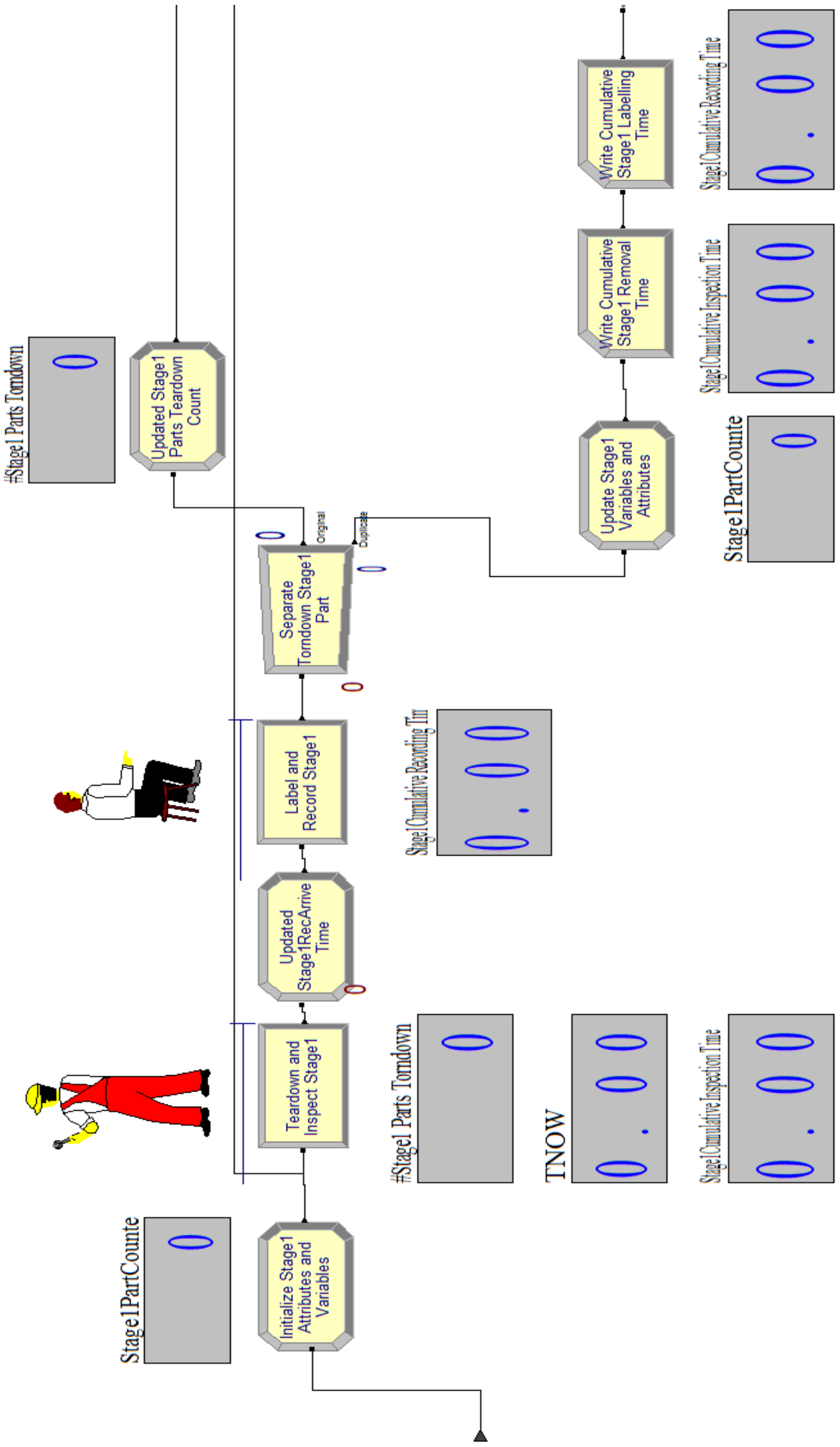


Figure 4-7a: Example of Detail-level Simulation Modular Block (Part A)

(Taken From Stage 1- Structural/Mechanical Teardown)

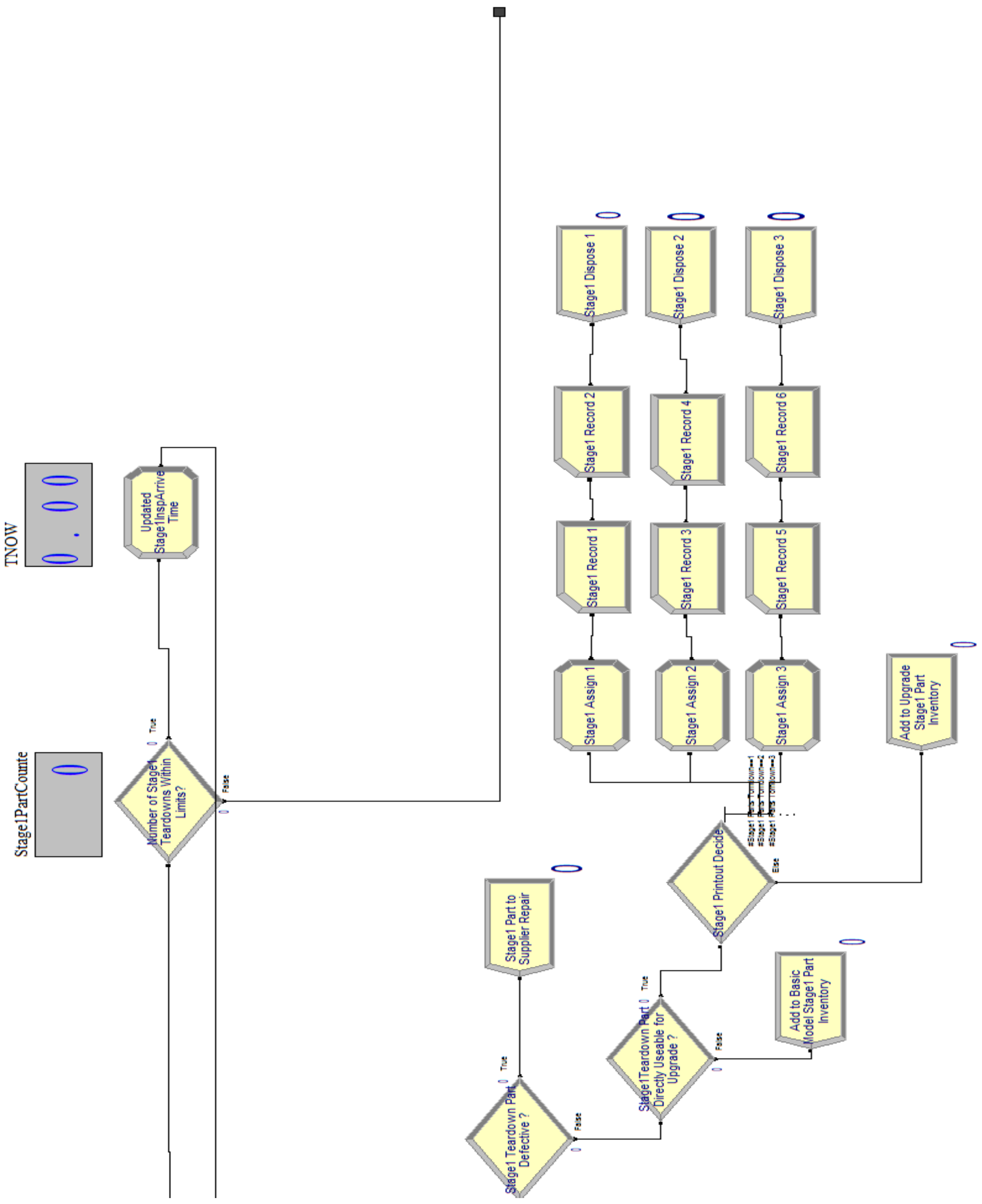


Figure 4-7b: Example of Detail-level Simulation Modular Block (Part B)

(Taken From Stage 1- Structural/Mechanical Teardown)

4.3.2 Discrete-Event Simulation Model Description

As mentioned in Section 4.2 the overall process Stage durations (presented in Figure 4-5) are known quite precisely from empirical data provided by Operator A by virtue of its technicians having carried out this upgrade process on over 40 aircraft by the time the data was provided to the author for the purpose of this research study. The skill-sets and the associated manpower required for each process step are therefore also known exactly based upon Operator A's prior work.

Clearly, on the basis of modifying 40 aircraft both Operator A and the author are confident that the average measured process times have stabilized and that the Operator A team is therefore well advanced on the "learner curve" for this upgrade program. For the purposes of the research work in this thesis the associated average individual task times quoted in Appendix One, estimated by Bell's subject matter experts (as described in Section 4.2), are regarded as very reliable, nevertheless in any process there will be some inherent process variability which could influence the average time taken to accomplish the individual tasks, either positively or negatively. Consequently it is assumed that the likely variation in these process times will be accurately represented by a "triangular distribution" and that, more specifically, there is more risk of the task taking longer than the estimated average time than if there is of the possibility of the task taking less time than the average. This is based on the assumption that the risk factors that would cause a task to take longer are more numerous and less predictable whereas the opportunities to shorten the task time are much fewer and have a lower impact on the task duration. The factors which could affect the task duration are likely limited to a marginal improvement in the skill-level of a particular employee or his/her drive/enthusiasm on a given day. The factors which would detrimentally affect the duration of a task include:

- Operator/technician fatigue/motivation

- Condition of the aircraft (i.e. damaged or hard-to-remove electrical or mechanical fasteners or parts)
- Worn/missing tools
- Non-standard configuration on a particular aircraft (i.e. due to prior aircraft modifications)

4.3.3 Simulation Model Results – RFID Implementation Scenarios Modelled

From the author's perspective any consideration of on-aircraft RFID tagging of on-aircraft assets drives the analyst towards considering the parts to be categorized as follows:

1. Line Replaceable Units (LRUs)
2. Lifed parts
3. Structural parts (non life-limited)

Such groupings are endorsed by the results of the literature review described in Section 2.5 which has revealed to some extent how at least one competitor helicopter manufacturer views the classification of on-aircraft parts, and by the nature of the upgrade process itself. As can be seen from the process flow chart shown in Figure 4-5 the actual helicopter upgrade RL process neatly categorizes the disassembly process into process steps which generally treat the components as if they fall into the above classifications/groupings.

When assessing the impact of RFID tagging of the parts it is valid to consider these groups from the following perspective:

1. The criticality of the part;
2. The number of parts in each group;

3. The complexity of the parts in terms of their attributes/characteristics that are important to know about from a remanufacturing (RL) perspective.

Engineering judgment dictates that it would be correct to prioritize the groups of parts which are the most critical from an airworthiness standpoint, that have the most complex attributes (e.g. modification standard, in-service repair history, accumulated service life etc) and the number of the parts in each category. Consequently it seemed logical in this modelling (simulation) framework that the smallest category which was key from an airworthiness standpoint and which has complex attributes would be considered first. The progressively larger classes of parts which have lesser airworthiness criticality and which have the fewest attributes would be lower down the priority list for asset tagging.

Viewing the parts in this way drove this study to prioritize the groups for RFID tagging as follows:

1. Lifed parts
2. LRUs (avionic/electrical)
3. LRUs (mechanical)
4. Structural parts (non life limited)

It is with this in mind that the following series of scenarios have been proposed in this study and modeled in order to assess the impact of successively more comprehensive RFID implementation:

- Scenario #1: Lifed parts - Large [12 RFID tagged parts from 10 component categories]
- Scenario #2: Lifed parts – Small [8 RFID tagged parts]
- Scenario #3: LRUs – Avionics/electrical [17 RFID tagged parts]
- Scenario #4: LRUs – Mechanical [11 RFID tagged parts]
- Scenarios #5 & #6: Structural parts (non life-limited) [57 RFID labeled parts]

The number of parts which are removed from the helicopter during the upgrade process is 199 parts although, as was mentioned in Section 2.6.2.1, the current study presented in this thesis has not made the assumption that all these assets would be tagged: the state-of-the-art of RFID technology and the size, geometry and in-service handling practices of aircraft components during their operational life does not support the assumption of tagging the entire family of disassembled components as being a viable one. In the simulation modelling results which are presented below each scenario was run with 100 replications.

Scenario #1 – Large Lifed Components

One of the shortcomings of certain analyses of the impact of RFID tagging on a product's components is that in many cases no consideration is given by the researcher to the practicality of actually being able to tag the asset (i.e. consideration of the part's size, shape, geometry in relation to attaching an RFID tag to it). In this study such consideration has been given, and in Scenario #1 only the larger life-limited components (i.e. the ones which by expert review) that could readily accommodate an RFID tag have been assumed to be actually tagged. The associated components are shown in Table 4.1. The components which fall into this category include the main and tail rotor blades and the engine: all of which are capable of accepting an approved RFID tag.

RFID Implementation Scenario #1 (Major Lifed Components)
Main Rotor Grip
Main Rotor Blades (2-off)
Lower Cyclic Tube
Collective Idler Link
Swashplay Support Assembly
Collective Lever
Main Rotor Mast
Tail Rotor Yoke
Tail Rotor Blades (2-off)
Engine

Table 4-1: RFID Implementation Scenario #1 (Large Lifed Components)

Running the simulation model with this scenario shows that the duration of Stage 6 can be reduced by ~11 hours: this represents a 5.5% reduction over the duration of the entire disassembly process over the baseline stage case where no RFID technology is present.

<u>Scenario #2 – Small Lifed Components</u>

From the author's perspective a more holistic solution in the context of lifed parts would be to be able to tag ALL the lifed components that would be scrutinized during Stage 6 (Figure 4-5). However certain of these lifed components are actually quite small in size. Although these components are small and have not (based upon the literature survey in Chapter 2) been tagged in any known aviation RL implementation to date, one of the industry examples shown in the literature survey does suggest a potential solution is achievable. The "Smart Tool Box" (a "Snap-On" company trade mark) which is commercially available does include the provision of RFID technology integrated <u>within</u> hand tool bits: if this technology can be engineered into the physical body of the "minor" lifed parts shown in Table 4.2 then the value of RFID technology can be leveraged on these smaller lifed items.

RFID Implementation Scenario #2 (Minor Lifed Components)
Main Rotor Trunnion
Strap Retention Pin
Tension Torsion Strap
Strap Retention Fitting
Latch Bolt
Collective Sleeve Assembly
Tail Rotor Gearbox Duplex Bearing
Freewheel Asselbly Clutch

Table 4-2: RFID Implementation Scenario #2 (Minor Lifed Components)

Therefore the simulation model was run for Scenario #2 assuming that it is possible to leverage this technology on smaller lifed helicopter components and the simulation results showed that the Stage 6 process time could be further reduced by 7.6 hours with an associated overall disassembly time reduction of 9.1% for the baseline case without RFID. Tagging simply this total of 18 different lifed component parts (i.e. combining Scenarios #1 and #2: which represents a total of 20 actual parts) yields a significant 9.1% reduction in the entire disassembly process time.

Scenario #3 – LRUs: Avionics/Electrical Components

In line with the previous rationale described earlier in this section, from an aircraft manufacturer's standpoint, the next class of components which merit consideration are Line Replaceable Units (LRUs). Such components are either avionic/electrical (e.g. radios, weather radars) or mechanical (e.g. fuel or hydraulic pumps) in nature and the first question which arises is whether it is the avionic/electrical LRUs or the mechanical LRUs which would be given a higher priority for tagging. In this study it is assumed that it is the avionic/electrical components which are generally more likely to have variations in configuration (i.e. hardware and/or software upgrades) than mechanical parts, or be the kind of assets where the actual configuration of a part may be very difficult to determine by physical inspection and may require very 'invasive' testing evaluation: this would be the case where a particular software standard or the presence of a particular electronic component standard would have to be identified.

From the author's standpoint, and for the purposes of this study, it has been assumed that from a remanufacturing (RL) perspective avionic/electrical components would be of a higher priority to tag than mechanical system components for the reasons highlighted above. Consequently Scenario #3 considers the case where the electrical/avionic components associated with the upgrade have been tagged: this would involve the prior tagging of 17 different LRU components in the case study being considered.

Running the simulation model with this scenario shows that the duration of Stages 2 and 5 can be reduced by a total of 1.73 hours and that this leads to a drop in the upgrade process's disassembly time of 0.9% over the baseline case where no avionic/electrical components are tagged.

When compared with the time savings associated with the "Lifed Components" (Large and small) modeled in Scenarios 1 and 2, it is clear that the benefit of tagging the electrical/avionic LRUs is not as significant as with the class of lifed components analyzed in Scenarios 1 and 2 (combined).

Scenario #4 – LRUs: Mechanical Components

This scenario complements Scenario 3 by assessing the impact on process time savings associated with RFID tagging the mechanical LRUs. Again, in order to ensure that only those mechanical LRUs which are feasible to tag are included in this study the entire list of mechanical LRUs disassembled in the upgrade process was given to a Bell Helicopter Product Support Engineer for specialist review. The latter specialist identified, from that exhaustive list, those mechanical LRUs which he believed were capable of being tagged and that list of RFID 'tag-able' LRUs was used as the input for the simulation.

The simulation model was run for Scenario #4 assuming this list of tagged mechanical systems components and the results show that the duration of Stage 1 would be reduced by ~0.5 hours and that this equates to an overall reduction in the upgrade process's disassembly time of 0.2% over the baseline (non-RFID) case. Combining this stage reduction with the cumulative effect of all the prior reductions yields a combined 10.2% reduction over the entire duration of the disassembly process.

Scenario #5 – Structural Parts (Non-Lifed - Large)

The scenario considered here is one which has not been vigorously considered before by Bell Helicopter nor, based upon the literature review, has it been analyzed and the results published by other aircraft or helicopter manufacturers: that scenario is the in-service RFID tagging of structural components. Examples of structural components in this context are:

- Engine cowlings
- Helicopter fuselage side-bodies
- Doors and access panels

The invasive teardown implicit in a helicopter upgrade of the magnitude of the Model 206 upgrade program naturally involves the removal of many structural items. Although many of the structural items are removed during the upgrading process in the majority of cases the same (or equivalent components) can be re-instated when the aircraft is reassembled as part of the next stage of the upgrade. The principle reasons for removing the structural components are:

1. To gain access to remove/replace other components (i.e. lifed components, or LRUs (avionic/electrical or mechanical) which are affected by the upgrade, or whose condition needs to be inspected for airworthiness purposes;
2. To permit damage inspection of the structural components themselves, or the base structure of the aircraft carcass beneath.

In only a few cases does the structural component of the as-delivered aircraft require to be replaced by a component with an enhanced configuration standard: in the vast majority of cases the structural components may simply be removed (during disassembly) and replaced (during upgrade reassembly) on the same aircraft provided that they are found to be free from damage during disassembly inspection.

Once again, in order to ensure a realistic assessment of which structural components can be realistically tagged a sample of the prototype low-cost/low-weight RFID label being developed (with the assistance of an RFID label manufacturer) was given to the Bell Helicopter PSE specialist mentioned previously (See Scenario #4). Given the dimensions of that sample label the specialist was able to objectively assess which of the structural components can be sensibly tagged using such a label: that list of tag-able structural items was used as input to the simulation modelling of Scenario #5. The simulation model was run for Scenario #5 assessing this set of major structural components and the results show an overall reduction in the upgrade process disassembly time of 1.8% over the baseline (non-RFID) case.

Scenario #6 – Structural Parts (Non-Lifed - All)

The final scenario considered here is one which considers all the structural components assessed by the Bell Helicopter PSE specialist as being capable of being RFID labeled, not just the major structural components. The simulation model was run for Scenario #6 assessing this set of all structural components, which are capable of being labeled, and the results show that the duration of the Stage 1 could be further reduced by a little less that 0.5 hour, and that this in turn would equate to a further reduction in the upgrade process disassembly time of 0.2% over the baseline (non-RFID) case.

4.3.4 Analysis of the Scenario Simulation Modelling Results

The results of individual RFID implementation scenarios discussed in the previous sections and the trends observed in terms of their impact on the reverse logistics (disassembly) process are shown in Figure 4-8 below. The cases shown are:

i. Baseline: the “no RFID” implementation case
ii. Lifed parts (partial)
iii. Lifed parts (complete)
iv. Lifed parts plus Major Electrical/Avionic LRU components
v. Lifed parts plus Major Elec/Avionic LRUs plus Major Mechanical LRU components
vi. Lifed parts plus Major Elec/Avionic LRUs plus Major Mech’ LRUs plus Major structural components

vii. Lifed parts plus Major Elec/Avionic LRUs plus Major Mech' LRUs plus All structural components

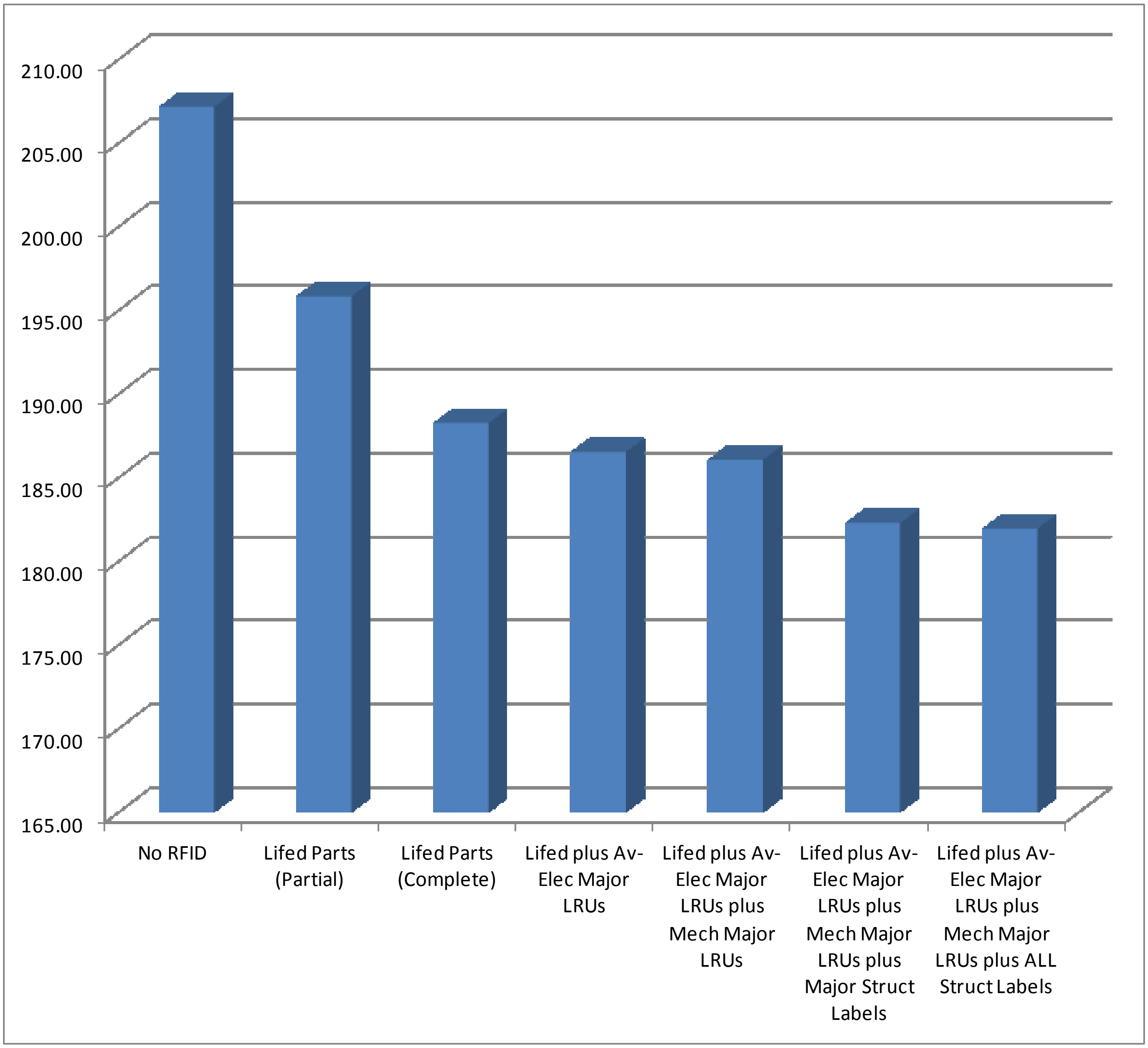


Figure 4-8: Disassembly Hours versus RFID Implementation Scenarios

From a known baseline with no RFID technology implementation the histogram presented in the figure shows that the lifed parts (of which there are a total of only 20 individual of component parts on the helicopter model considered in the case study) as a group are by far the most impactful in reducing the disassembly time. Figure 4-9 shows the time saving yielded by each successive combination of scenarios represented as a percentage of the overall upgrade process disassembly time.

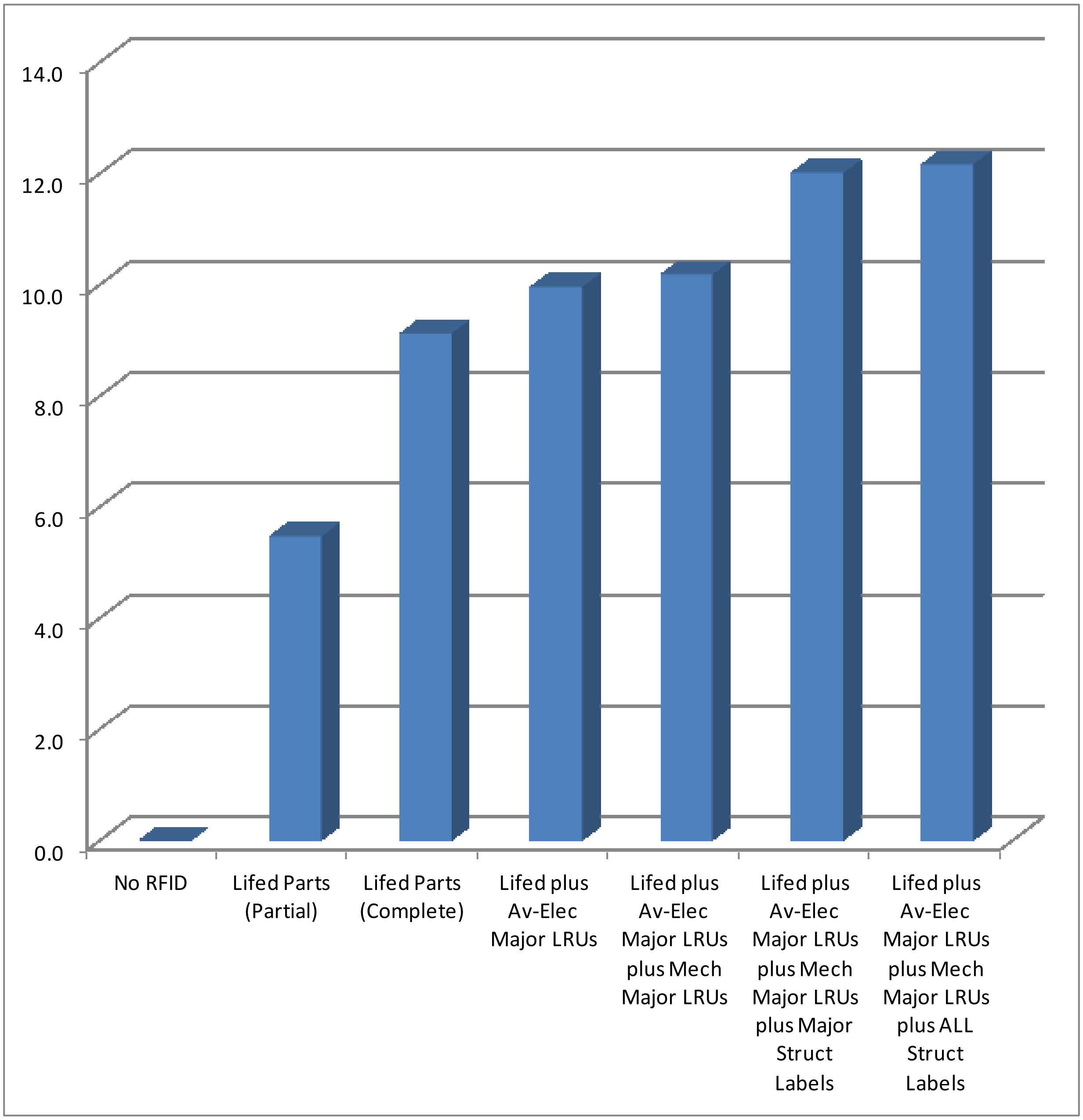


Figure 4-9: Cumulative Percentage Labour Saving versus RFID Implementation Scenarios

The data from this figure is summarized in Table 4-3 below:

	RFID Implementation Scenario	Percentage Disassembly Time Reduction Over Baseline (No RFID Implementation) Case
	No RFID Implementation	Baseline (Datum)
Scenario 1	Lifed Parts (Partial)	5.5
Scenario 2	Lifed Parts (Complete)	9.1
Scenario 3	Lifed plus Av-Elec Major LRUs	10.0
Scenario 4	Lifed plus Av-Elec Major LRUs plus Mech Major LRUs	10.2
Scenario 5	Lifed plus Av-Elec Major LRUs plus Mech Major LRUs plus Major Structural Labels	12.0
Scenario 6	Lifed plus Av-Elec' Major LRUs plus Mech' Major LRUs plus ALL Structural Labels	12.2

Table 4-3: Cumulative Percentage Labour Saving versus RFID Implementation

Clearly, based upon the reduction in the disassembly times for these scenarios, the cumulative effect of implementing them all would be a 12.2% reduction in the disassembly time of each helicopter. In other words, after implementing the RFID technology, for every ten helicopters disassembled the time saving yielded by the technology would be equivalent to (a little more than) the disassembly time for one entire helicopter. The magnitude of the results is corroborated by the work presented by Dejam [9] which was arrived at independently: that work predicts (by all three simulation methods that the author used) a percentage time saving of ~10%. The time saving predicted by this current study in this thesis is certainly a very worthwhile improvement. The question is then: does the time saving achieved via RFID technology justify the financial cost of the RFID implementation? Figure 4-10 attempts to assess this by showing the "net cost reduction" of each RFID implementation scenario: in this case the net cost reduction is defined by:

Net cost reduction = Cumulative Cost Reduction – Cumulative RFID Tag Cost per Aircraft - **EQN 5-1**

Based upon this calculation the optimal cost reduction per aircraft is achieved by RFID tagging all the lifed parts plus all the electrical and avionic LRUs (i.e. Scenario #3). The inclusion of the tagging of the mechanical LRUs and the RFID labeling the structural parts begins to reduce slightly the cost benefit of the RFID implementation in an RL context when the number and cost of the individual component RFID tags are taken into account, however the cost benefit improves when RFID labeling of the major structural parts is included, but falls once again when all the structural parts are considered to be labeled. The latter drop in the net cost reduction is due to the fact that the time saving gain with the inclusion of the minor structural parts is rather modest, and is outweighed by the cost of the associated RFID labels required to tag the affected parts. The values are based upon some proprietary cost information from the tag supplier and Bell Helicopter, the details of which cannot be explicitly revealed. Since a firm estimate for the cost of a production-ready RFID label is not available at this time no reliable conclusions can be drawn regarding the cost benefit of the latter two scenarios (Scenarios 5 and 6). It should be noted that the cost of the actual tagging of the parts is considered to be negligible since, in line with existing practice, the parts have to be labeled in any case.

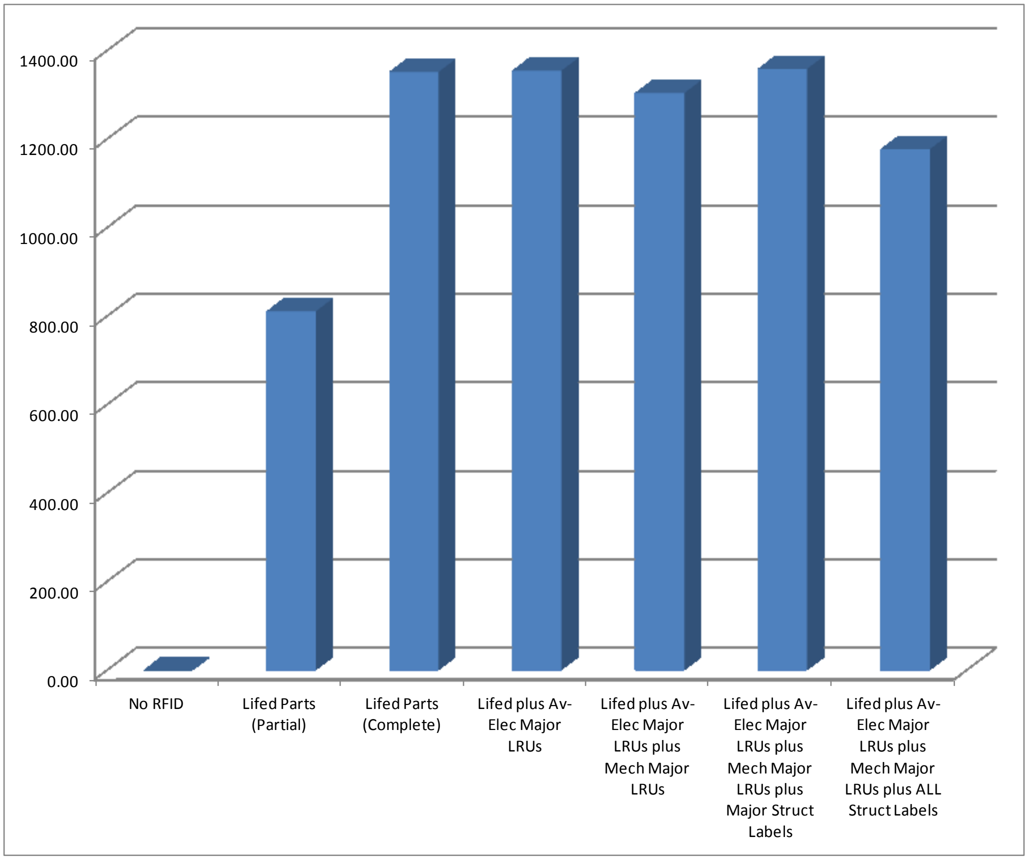


Figure 4-10: Net Cost Reduction (US$) of the RFID Implementation Scenarios

At this time the current approach being considered within Bell Helicopter with regard to RFID tagging (on a new model of helicopter currently under development) is that all of a helicopter's LRU components, electrical/avionic <u>and</u> mechanical, should be the candidates for RFID tagging. In an RL context the current study indicates that this is not the ideal solution and that a better approach would be to target the RFID tagging of all the aircraft's lifed components. This is further borne out by two more subjective considerations: firstly, the benchmarking work described in Section 2.4 indicated that one of the company's competitors is focusing on the tagging of lifed components; and secondly, and more from a perspective of engineering judgment than analysis, the belief is that RFID tagging of lifed components is likely to yield a significant benefit during the service life (i.e. ongoing maintenance and repair tasks) of the helicopter, even before the aircraft reaches the end-of-service-life (RL) phase. Consistent with Bell Helicopter's existing plan to apply RFID tags to LRUs on its major new helicopter platforms currently under development, the results of the simulation study do indicate that there is, in an RL context, a business case for the tagging of the avionic/electrical LRUs.

The literature review (Section 2.2.2) mentioned the way in which RFID can play a contributing role in the inventory and spares control within an organization: these advantages have not been assessed as part of the contribution the technology can make to Operator A in an RL context but this would certainly feature in any subsequent extension of the current work. Section 2.2.2 also detailed the "obstacles" identified by Asif [15] to the adoption of RFID in RL and listed them as:

- Quality and processing sequence
- Collection points and differing standards
- RFID and global market

Clearly the analysis presented in this chapter has shown the way in which this RL process for a helicopter upgrade has overcome (or at least avoided) these difficulties by:

1. The controlled nature of the product in the in-service environment (i.e. mandatory adherence to airworthiness standards);
2. The regulated way in which approved Service Centers act as RL "collection points";
3. The intervention of the FAA in terms of their advisory material relating to the adoption of RFID technology in aviation.

Additionally the literature review highlighted that the work of some researchers into RL (specifically Rogers & Tibben-Lemke [10]) has stated that the "paper-intensive" nature of RL processes has been a barrier to RL automation: the present study has however shown that replacing man-readable labels with non-line-of-sight RFID technology has leveraged significant time (and therefore labour) savings in an aviation-related RL process. Implicit in the simulated scenarios considered are estimates of the time savings yielded by RFID in terms of the time saved through the parts being able to "auto-identify" themselves and through the quick and accurate availability of item-specific attributes (modification standard and maintenance/repair history) that RFID technology can provided at the component level.

In view of the above there is certainly merit in Bell Helicopter exploring the RFID tagging of lifed components further, although the over-arching issues associated with institutionalizing RFID technology in a business (such as tag data information protocols, middleware design and data warehousing) identified by Ramudhin ***et al.*** [34] will need to be addressed by further research work. Moreover the technical aspects of fitting/embedding the appropriate RFID functionality to the parts, and philosophy of how the mass of data associated with lifed parts could be usefully managed using an RFID-based system have still to be fully investigated. The latter could usefully be explored by expanding the modelling framework developed in the current study to include the entire forward logistics aspects of the product's life cycle, including a comprehensive assessment of the benefits of RFID technology in an MRO context. Such an extension of the current work would provide insight into the financial viability (or otherwise) for the RFID tagging of all the LRUs (avionic/electrical and mechanical) and potentially the viability of the RFID-labeled structural components.

4.4 Further Optimization of the Upgrade Program Process

4.4.1 Additional Optimization of the Process Post-RFID Implementation

The foregoing analysis has highlighted that the current real-life aircraft upgrade remanufacturing process at "Operator A" comprises a base-line disassembly process (with no RFID implemented) which takes 147 hours to complete, which is equivalent to 3.7 working weeks (assuming a standard 40 hour work week): essentially a 4-week "takt" time for the disassembly process. This explains the reason why, with the current skill set allocation and manpower loading devoted to this disassembly phase of the overall upgrade program, the cadence of the upgrade program is set up to receive one helicopter for rework every calendar month. The subsequent assembly phase of the upgrade process, to make the 'new' helicopter, uses a separate crew of technicians and takes up from where the disassembly process finishes off. That assembly part of the process takes 6 calendar weeks: assuming that the final pass-off certification checks of the upgraded helicopter (including certification flight testing) takes a further 2 weeks gives an overall period of 12 weeks (3 months) to produce an upgraded helicopter from the initial time of receipt of the original helicopter at Operator A.

As was highlighted in Section 1.1.3, the analysis of the reverse logistics disassembly process uses this real-life aircraft upgrade remanufacturing process at Operator A as a case study, but that process is <u>not</u> currently fully time/resource constrained and could therefore benefit from further process optimization. Based upon the simulation model's results, the influence of RFID technology (Table 4.3) when applied to only the lifed components and major Elec/Avionic LRUs would result in a time saving of 10% over the current non-RFID process. Specifically, with regard to Figure 4-6, the critical path of the process (with RFID implemented) is defined by a combination of the Initial Inspection phase <u>plus</u> disassembly Stages 1, 4 and 6. Based upon this the disassembly process critical path time would be reduced from 147 hours prior to RFID implementation (i.e. slightly under one aircraft per working month) to 124 hours post-RFID implementation: a little more than one aircraft every 3 working weeks. If the goal, as part of Operator A's business case, is to process ***more*** aircraft per month in order to increase the company's revenue from the helicopter upgrade process, then it is this critical path that we must further optimize initially. Consequently, one simple and cost effective solution would be to consider that if another full-time resource is added to Stage 6 (the lifed parts Overhaul phase) the total elapsed time for the disassembly process critical path further reduces from 124 hours to 120 hours. This indicates that by <u>combining</u> the benefits of the time savings leveraged by the RFID technology with the additional consideration of a potentially (very modest) manpower and skill set re-allocation, further critical path disassembly process time savings can be achieved. The addition of an overhaul technician for the duration of Stage 6 (i.e. 2 men, each working for 3 hours, in lieu of 1 man working for 6 hours) would bring the critical path for the reverse logistics disassembly process to 120 hours: this corresponds with 1 aircraft being able to be disassembled every 3 working weeks.

Being able to process the disassembly of 1 aircraft every 3 weeks would enable 4 aircraft to be disassembled in 12 weeks (i.e. essentially 3 calendar months), which would result in 16 aircraft being capable of being disassembled per year (in lieu of the current 12 vehicles per year, i.e. one per month): this represents a 33% improvement in the number of aircraft capable of being received into the upgrade facility.

4.4.2 <u>Business Case Analysis of the Optimized Process</u>

The factors affecting the business case of the process improvement described in the previous section would be as follows:

1. The RFID tag cost per aircraft (The RFID tag cost of Scenario #3 would be $370 per a/c based upon the required number of assets to be tagged.)
2. The cost of the RFID reader infrastructure installed on the shop floor at the workstation used to carry out the reverse logistics (upgrade) activity. (Clearly the RFID reader would have to ‘talk’ to enterprise-level inventory system software which would have an over-arching role in

monitoring the entire facility's inventory. Consequently it is not believed that the costs of this ***enterprise level*** investment should be accounted as part of the reverse logistics business case, although the business case for the enterprise level RFID software investment would include careful accounting of the time-savings leveraged by **all** the RFID use-cases employed throughout the facility, including the reverse logistics (upgrade) processes).

3. The business case benefit of increasing the yield of the process.

Based upon a previous business case assessment carried out for Bell Helicopter for another RFID-related infrastructure installation project [41] it is estimated that the hardware cost for one RFID-sensing portal of sufficient size for use in this disassembly process would be of the order of $1,600 (Assume $2,000 after inclusion of the actual RFID portal installation costs). Amortizing the RFID portal cost over (say) 50 aircraft would result in an RFID hardware cost per helicopter upgrade of $40 (i.e. $2000 / 50). Considering the overall aircraft-specific hardware and RFID portal cost into account would result in an RFID hardware cost per upgrade aircraft of $410 (i.e. $370 + $40). This provides the cost of items 1 and 2 in the list of three factors described above.

The third factor, the business case yield, can be calculated as follows: let us assume that "Operator A" has decided to buy used Model 206L-1 or L-3 helicopters, upgrade them and then sell the upgraded aircraft back into the market place at a profit (we know it is already upgrading its own fleet of Model 206L-1/L-3 aircraft to leverage the fleet performance advantages of the upgrade, which will obviously result in the company having helicopter assets which have more financial "book" value after the vehicles have been upgraded).

As part of the study into the upgrade process carried out at Bell Helicopter [42] an analysis was carried out to estimate some of the financial aspects of the upgrade process. In that study reasonable estimates were derived for the basic price of a used Model 206L-1/L-3 helicopter (in airworthy condition); the cost of upgrading the Model 206L-1/L-3 to the improved L-1^{+}/L-3^{+} standards, and also the expected re-sale value of the L-1^{+}/L-3^{+} configuration helicopter. Based upon these estimates the expected profit margin for each upgrade is as follows:

- Basic price of a used Model 206L-1/L-3: \$ 300,000
- Cost of upgrading the Model 206L-1/L-3: \$ 1,211,000 (includes manpower, materials and energy)
- Expected re-sale value of the L-1^{+}/L-3^{+}: \$ 1,650,000
- Delta profit/loss per aircraft: \$ 139,000 (profit)

From the analysis presented in the previous section the investment of implementing RFID, specifically Scenario #3, at an amortized cost of \$ 410 per aircraft, would reduce this profit per aircraft (very slightly) to a little over \$ 138,000 (\$ 138,590 to be exact), however that RFID implementation scenario would enable 16 aircraft to be disassembled per year (in lieu of the current 12 vehicles per year). Hence the total revenue increase to Operator A from being able to handle this additional 4 aircraft per year would be almost \$ 555,000 (\$ 554,360 to be precise). The return on this necessary RFID investment would therefore be calculated as follows:

RoI = Increased profit from increased RFID implementation (i.e. from 4 additional
aircraft) / RFID implementation costs per aircraft (for all the aircraft disassembled).

RoI = \$ 554, 360 / (16 aircraft) x (\$ 410 RFID tags/tag reader cost per aircraft) = 84.5

Clearly this is a very compelling financial case for the adoption of RFID (to the extent described by Scenario #3) in terms of its impact in the very intrusive disassembly process associated with this helicopter upgrade process. Implicit in this simulation model (and financial model) of the process is that the RFID tags are already attached to the relevant assets prior to the start of the upgrade process at Operator A: this is achievable either by fitting the tags to the relevant components at new helicopter manufacture at essentially zero labour cost (which is what Bell Helicopter is planning to do with one of its current helicopter models currently under development) or by fitting the tags to the necessary components during the prior service life of the helicopter during routine maintenance activity. Given that, for the RFID implementation scenario involved, a total of only 37 assets require to be fitted with RFID tags, it is quite feasible to accomplish this progressively during routine maintenance during the an aircraft model's service life at minimal cost labour cost prior to the aircraft reaching the end of useful service life when it would be a candidate for an upgrade: this is particularly true given that most of the RFID tagged components in the scenario considered are lifed components which would have to be removed and replaced periodically anyway during normal maintenance operations. Furthermore there are advantages to having such RFID technology in place on these components (particularly the lifed components) during its normal service life's maintenance activities even before the aircraft reaches its end-of-life (reverse logistics) upgrade phase: quantitative analysis of these additional service life benefits is outside the scope of the current study, although qualitatively they are known to exist.

CHAPTER 5 – PRACTICAL IMPLEMENTATION OF RFID

5.1 Introduction

One of the outcomes of employing the "design for six sigma" approach used in this research study is that it forces the analyst to consider design solutions and also *hybridized* design solutions that could potentially address the initial functional requirements (and ultimately the high-level customer needs). Once the original research proposal had been suggested by Concordia University to Bell Helicopter it was quickly realized that the RL process implicit in Bell Helicopter's current "Model 206L *LongRanger* Upgrade Program" provided an ideal real-life case study of an actual helicopter commercial remanufacturing operation as a basis for the simulation modelling for the different levels of RFID framework implementation. As part of the generation of ideas (the so-called "design solutions" described in Section 3.2) in the DFSS process it was realized that the availability of low cost/low weight machine-printable (and man-readable) RFID labelling would enable an entire class of helicopter components (i.e. structural parts) to be 'tagged' in a way which Bell Helicopter had not previously considered possible. As result of this a survey was made of the available RFID technology to find if such a label existed commercially, or if a ***partially suitable*** production solution existed which could be further developed quickly and with minimal cost. The result of this market survey of existing RFID labels revealed the existence of a product, manufactured by a company known hereafter as "Company F", which appeared to represent a promising, but not fully refined, technical solution.

One of the DFSS functional requirements for the RFID technology to be evaluated as part of the RFID modelling framework being assessed for this research project is that the assumed (RFID) technology must be feasible. The label manufacturer Company F offered to work with the author as part of this research in order evaluate if their product could be demonstrated to meet Bell Helicopter's technical requirements for such an RFID label solution, and if necessary to make adaptations to the product's material construction and functionality in order to comply with these technical requirements. In order to do this the author had to establish what the functional requirements would actually be and to work with Company F to test the mature prototype RFID label offered by Company F for evaluation by Bell Helicopter. The next section describes this empirical part of the project in more detail.

5.2 RFID Label Functional Requirements & Objectives for the Test Program

5.2.1 Background

The initial dialogue with Company F focused on defining the functional requirements for the RFID label. In summary the author's vision of the application of the technology was that the RFID labels should be capable of replacing the labels which are currently applied to structural parts: these existing labels comprise of an embossed aluminium tape (Figure 5-1) which is applied to the part (metal or composite) at one of the latter stages of its manufacturing process. As can be seen from the figure these labels are man-readable and only comprise of the component's part number. At the present time Bell Helicopter is changing from this embossed aluminium tape to a printable polyamide-based (Figure 5-2) which is man-readable and line-of-sight machine readable (i.e. bar code). From Bell Helicopter's perspective the attraction of an alternative (more technically sophisticated) RFID label is that it could be both man-

Figure 5-1: Traditional Embossed Aluminium Tape

Figure 5-2: Printable Polyamide-based (Bar-coded) Label

readable and offer non-line-of-sight machine (RFID) readability. A further requirement was that the RFID label would be capable of being applied to the structural part at an early stage in the part's original manufacturing process: in this way the advantages of the RFID functionality can be leveraged to highlight inefficiencies during the part's manufacturing process.

In the context of helicopter structural components there are essentially 3 main classes of parts:

1. Metal parts (aluminium);
2. Bonded parts;
3. Composite parts (of which these can be further sub-divided into 3 main categories):
    i. Glass-fibre/epoxy resin
    ii. Carbon-fibre/epoxy resin
    iii. Carbon-fibre/BMI (Bismaleimide) resin

From Bell Helicopter's standpoint implicit in the requirement that the RFID functionality must drive efficiency improvements in the manufacturing process is that the RFID label must be readable when attached to the different materials from which structural components are made. Furthermore the label technology must be capable of withstanding the often harsh environments to which the raw materials of the components are subjected during the processing of the emerging manufactured parts (e.g. the high pressures and temperatures of the autoclave processes employed during the manufacture of a composite part). Company F's initial feedback was that their label-type RFID tags (and those of their competitors) were not routinely being used as light-weight/low-cost solutions for identifying structural parts in the manner envisioned and that collaborative experimental work would be required between Company F and Bell Helicopter in order to characterize a workable solution: rugged RFID tags are available from many manufacturers but printable low-cost/low-weight labels that will work on the range of materials used to make aircraft structural parts (at an acceptable read-range) are not currently on the market.

It must be emphasized that the ability of the RFID label to be applied to the part during its manufacturing process is to enable Bell Helicopter to be able to track and trace the emerging part (or batches of parts) during manufacture without the need for line-of-sight reading of the emerging part's manufacturing "Traveler" (i.e. the name given to the paperwork which accompanies a part during its manufacturing process from raw materials through to completion of the final part). This aspect of the RFID label functionality is perceived as being a potential "Lean Manufacturing" enabler during the part's original manufacturing process. Clearly the ability of the RFID labels to withstand harsh environments is key to their reliability and survivability of the in-service environment, up to and including the RL process implicit in an aircraft upgrade (remanufacturing) process.

5.2.2 Definition of Functional Requirements

Based upon the above the functional requirements for the RFID labels can be broadly categorized into 3 areas as follows:

1. **RFID Readability.** The prototype RFID label must give an acceptable read-range (defined as being 4ft for the purposes of this research study) when applied to a range of structural component materials :

    a. Metal (aluminium)
    b. Glass-fibre/epoxy resin
    c. Carbon-fibre/epoxy resin
    d. Carbon-fibre/BMI

The principle of the read-range defined above is that the disassembly process would use fixed readers, likely in the form of a portal (with an embedded reader/antenna) that would be adjacent to the aircraft. The mechanic would have to carry the disassembled item through this portal to the storage racks located beside the aircraft being worked on. The simple act of carrying the item through the portal (reader) would trigger the system to locate/read the part.

2. **Label Survivability.** The prototype RFID label must provide a read signal and be fit for its intended purpose in terms of its construction and appearance after being exposed to the process temperatures and pressures (for the required manufacturing process durations) for glass-fibre, carbon-fibre/epoxy and carbon-fibre/BMI.
3. **Material Compatibility**. The prototype RFID label material must remain fit for its intended purpose in terms of its construction and appearance after exposure to key fluids and solvents to which it will be exposed during its anticipated service life.

These 3 subject areas were investigated under two distinct test programs:

- Functioning Label "Harsh Process Environment & Readability Testing", and
- Label Material Compatibility Testing

Of these two test programs the author of this thesis only directly contributed to the former test program, so only the results of that test program will be described in this dissertation (It should however be noted that the second test program on “Label Material Compatibility Testing” is currently ongoing within Bell Helicopter’s Materials & Processes (M&P) laboratory).

5.2.3 Harsh Process Environment & Readability Testing

The objective of this test was to assess the ability of prototype RFID part labels (shown in Figure 5-3), provided by Company F, to withstand representative temperatures and pressures for the different cure cycles associated with the manufacture of various bonded panel materials (i.e. metal and composite), and to assess the labels’ ability to withstand the post-cure processing temperatures (as appropriate to the material). The RFID labels which were subjected to test had already been coded by Company F prior to embarking on the test program at Bell Helicopter. After the testing the readability of the labels was subjected to a preliminary assessment by the author (using the facilities of the CIISE RFID Laboratory) and more thoroughly by Company F in their anechoic chamber.

The ultimate goal would be to position these RFID labels in the same location on the parts where their existing labels are currently located. For structural parts the existing labels would those of the kind shown either in Figure 5-1 (traditional embossed aluminium label) or Figure 5-2 (the more contemporary polyamide label). In a major upgrade disassembly process, or even in a more routine in-service maintenance and repair scenario, the mechanics will be familiar with the location of the previous non-RFID labels when looking to identify a part (and these RFID labels will still retain all the man-readable information shown on the current non-RFID labels). Consequently it is logical to position the new labels in the same part locations and to strive to engineer their size and geometry to be able to accommodate such positioning.

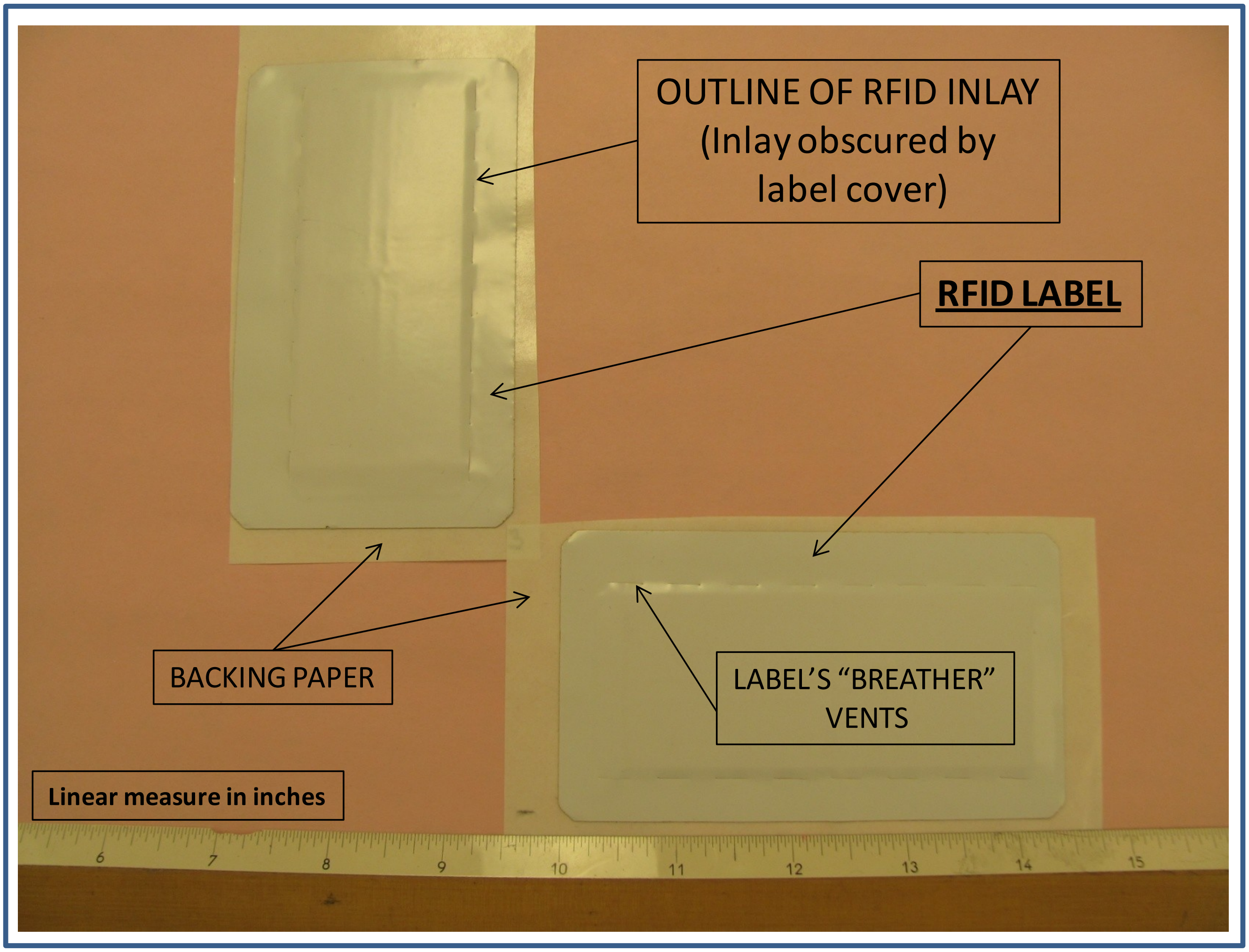


Figure 5-3: Prototype RFID Labels

Successful completion of this testing would show that the labels are still readable after cure (and post-cure) cycle exposure. No attempt was to be made to assess optimizing the RFID label read range at this stage: the testing was simply to assess the survivability of each label's embedded RFID inlay, and the label material itself, to the relevant process temperatures and pressures to which they are exposed during manufacture.

5.3 Test Program

In line with the overall requirements highlighted in Section 5.2.2, four prototype RFID labels were provided by Company F for assessment by BHTCL. These labels had been specifically designed to be "robust" (i.e. withstand the high temperatures and pressures associated with bonded panel manufacturing processes).

The overall aim of the test program was to assess survivability of the RFID labels when attached to test coupons made from the following four materials:

- Metal (aluminium) (BPS 4458)
- Glass fibre/epoxy (BPS 4437)
- Carbon fibre/epoxy (BPS 4511)
- Carbon fibre/BMI (BPS 4520)

A comparison matrix of the cure and post-cure process temperatures and pressures for these materials, and their associated maximum service temperatures is given in Table 6-1. (In order to protect Bell Helicopter's intellectual property the process temperatures and pressures have been presented as qualitative values, not quantitative ones).

	Metal Bonded	**Glass Fibre / Epoxy**	**Carbon Fibre / Epoxy**	**Carbon Fibre / BMI**
Material Specification	299-947-320, Type: 1	299-947-076, Type: C	299-947-346, Type: 37, CL: I, FR: A, GR:3	299-947-336 Type: 36, CL: 4, FR: A
Cure Cycle (Autoclave)	Base Temp (ºF), Base Time (min) (BPS4458)	Base Temp (ºF), Base Time (min) (BPS4437)	Mid Temp (ºF), Mid Time (min) (BPS4511)	High Temp (ºF), High Time (min) (BPS4520)
Cure Pressure	Base Pressure psi	Base Pressure psi	High Pressure psi	Base Pressure psi
Post-Cure Cycle (Oven)	N/A	N/A	N/A	Post-cure Temp (ºF), Post-cure Time (min)

Table 5-1: Process Temperatures & Pressures

Each material test coupon used in the testing was to be constructed to have a minimum of a 0.5 inch perimeter of excess material around the RFID label attached to the coupon, as shown in Figure 5-4.

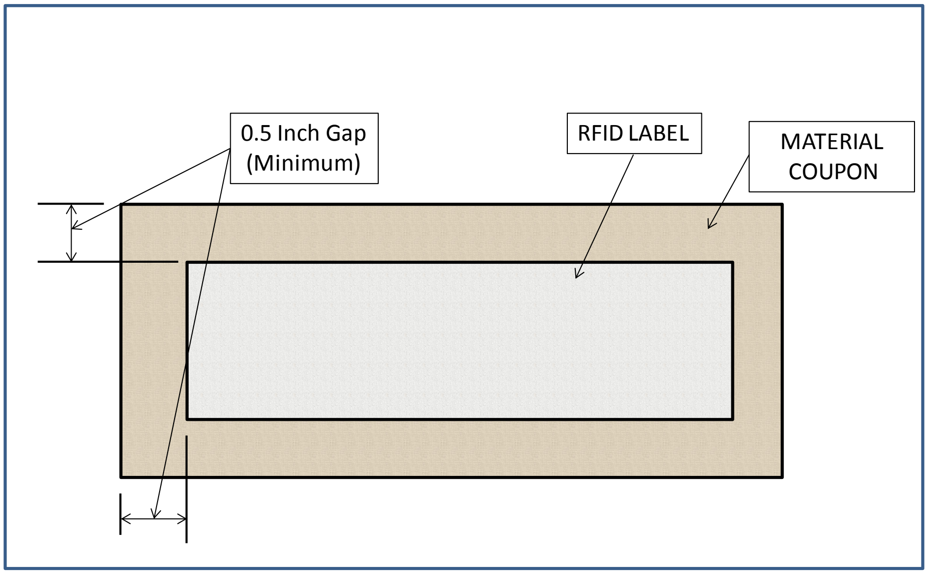


Figure 5-4: Material/RFID Label Geometry - General

Each test coupon was prepared by the procedure set out in this section and was inspected after each test in order to assess the physical condition of the RFID label after exposure to the curing process and to assess if the label had caused any detrimental effect on the test coupon material. Photographs were taken of the coupons after the curing stage.

After the curing stage the RFID labels were subjected to a preliminary readability assessment in the Concordia RFID Lab using the following equipment:

- CAEN RFID module docked into a Psion “Workabout Pro 3” Teklogix hand-held computer
- Power setting = 500 mW

5.3.1 Metal Coupon

A test coupon made from aluminium was made for this test, respecting the geometry shown in Figure 5-4. The build-up of the test article is shown in cross section in Figure 5-5, and comprised (from the material coupon upwards):

- Material coupon: base layer of aluminium
- Etched layer (Surface preparation per BPS 4352 Sect. II, Method II)*
- Adhesive primer per 299-947-320 CL: I*
- Adhesive film (high temperature) per 299-947-320 Type: I*
- RFID label
- Silicon adhesive tape (Airtech-Flashbreaker 2) to be applied over the RFID label (extending 0.5 inch beyond the label)

[*The specifications referenced here are proprietary to Bell Helicopter and their details will not be disclosed in this dissertation.]

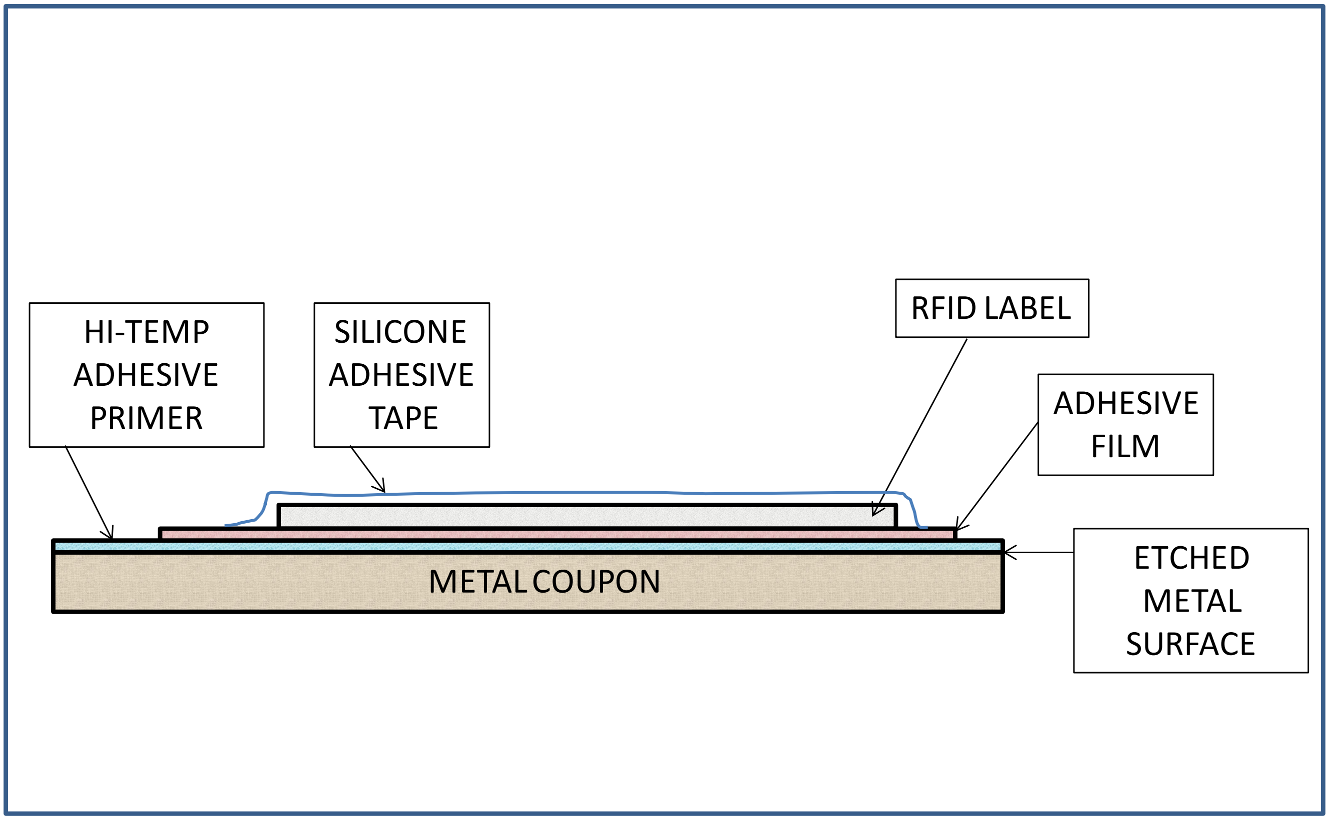


Figure 5-5: Metal/ Panel Coupon

5.3.2 Glass Fibre/Epoxy Coupon

A test coupon made from glass fibre/epoxy was made for this test, respecting the geometry shown in Figure 5-4. The build-up of the test article is shown in cross section in Figure 5-6, and comprised (from the material coupon upwards):

- Material coupon: base layer of glass fibre/epoxy
- RFID label
- Silicon adhesive tape (Airtech-Flashbreaker 2) to be applied over the RFID label (extending 0.5 inch beyond the label)

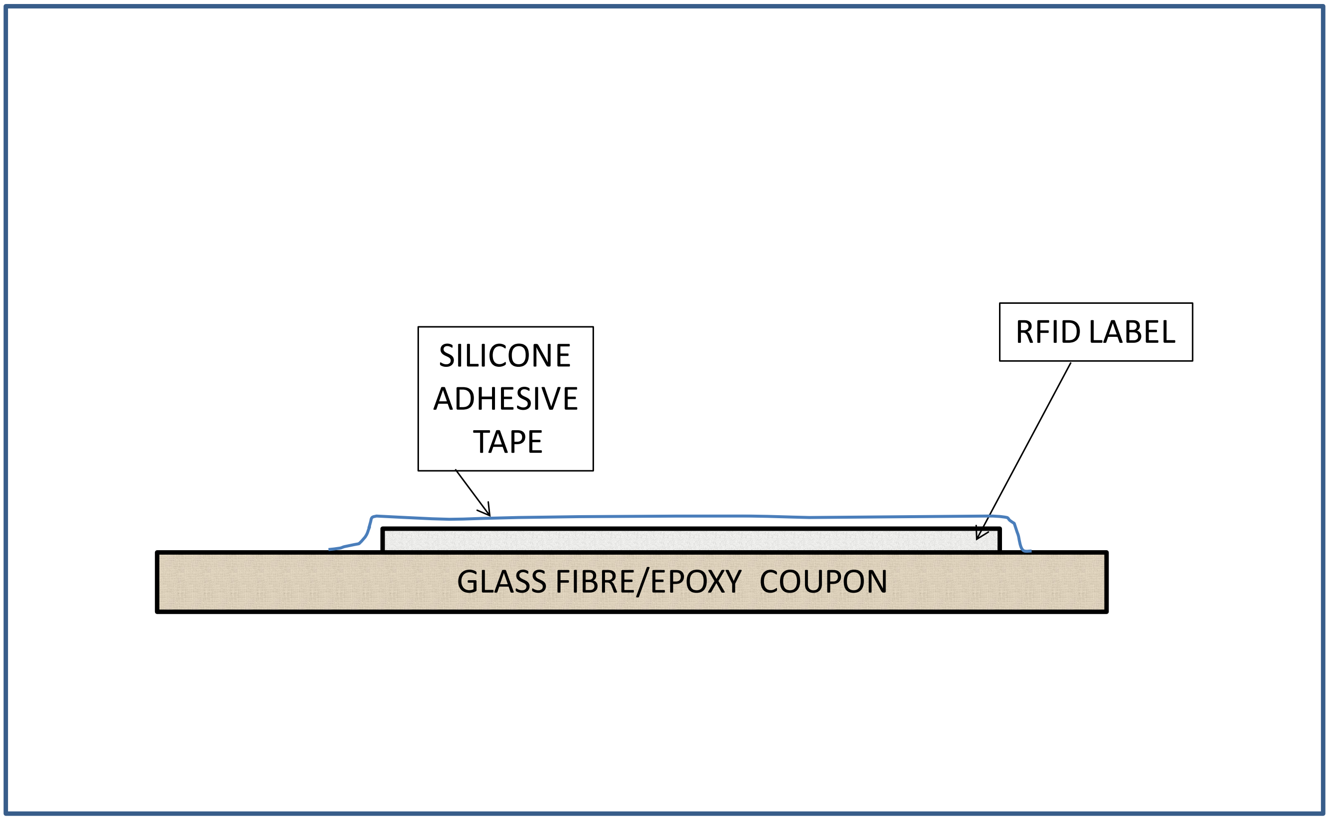


Figure 5-6: Glass Fibre/Epoxy Panel Coupon

5.3.3 Carbon Fibre/BMI & Carbon Fibre/Epoxy Coupons

Lastly, two test coupons were made from carbon fibre/BMI and carbon fibre/Epoxy for this test, respecting the geometry shown in Figure 5.4. The build-up of these test articles is shown in cross section in Figure 5-7, and comprised (from the material coupon upwards):

- Material coupon: base layer of carbon fibre/BMI (or carbon fibre/Epoxy)
- RFID label
- Silicon adhesive tape (Airtech-Flashbreaker 2) to be applied over the RFID label (extending 0.5 inch beyond the label)

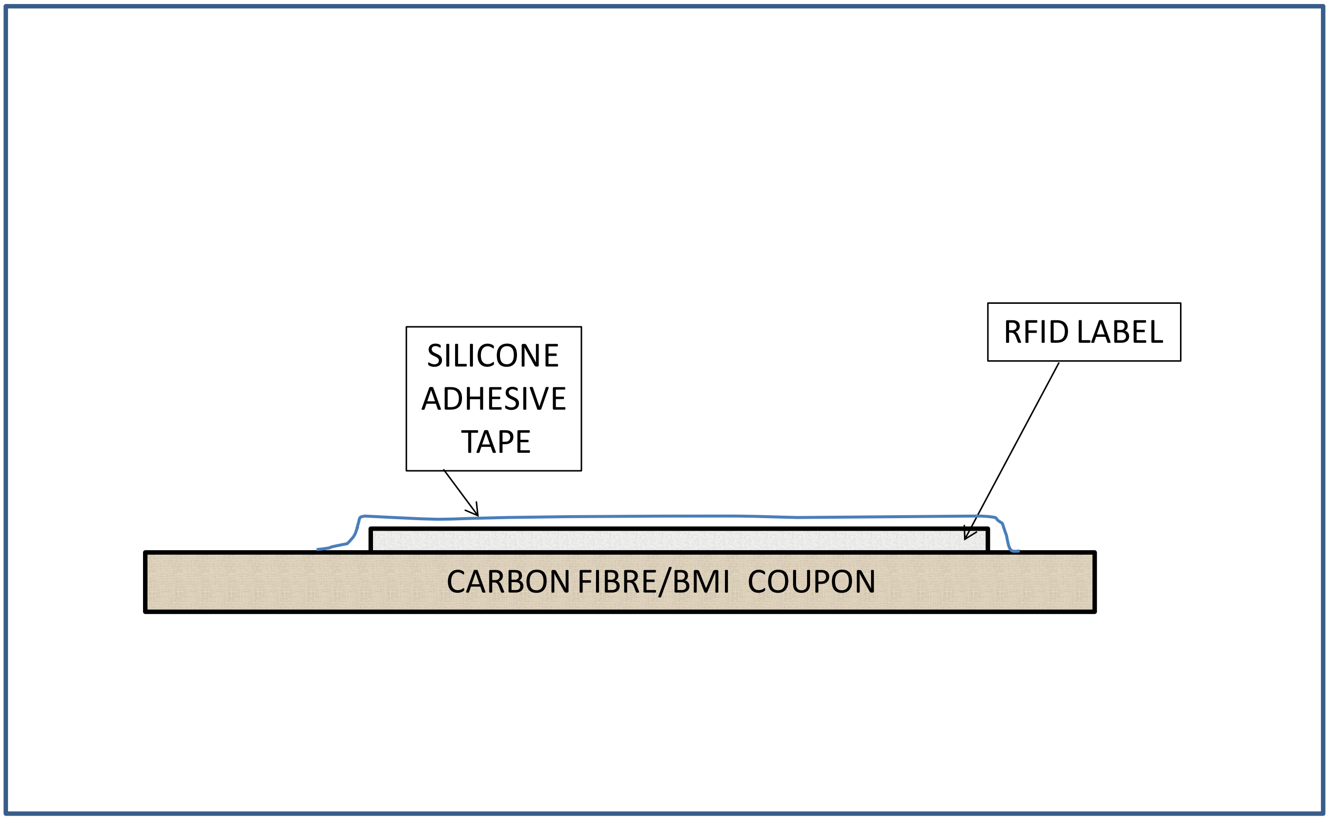


Figure 5-7: Carbon Fibre/BMI Panel Coupon

5.4 Test Results

The tests were carried out on the first four test coupons (metal, glass fibre/epoxy and carbon fibre/BMI, carbon fibre/Epoxy). All four of the test coupons gave positive survivability indications (i.e. positive RFID tag read results) in the Concordia Lab, and the physical condition of the four test coupons are shown in Figures 5-8 through 5-13.

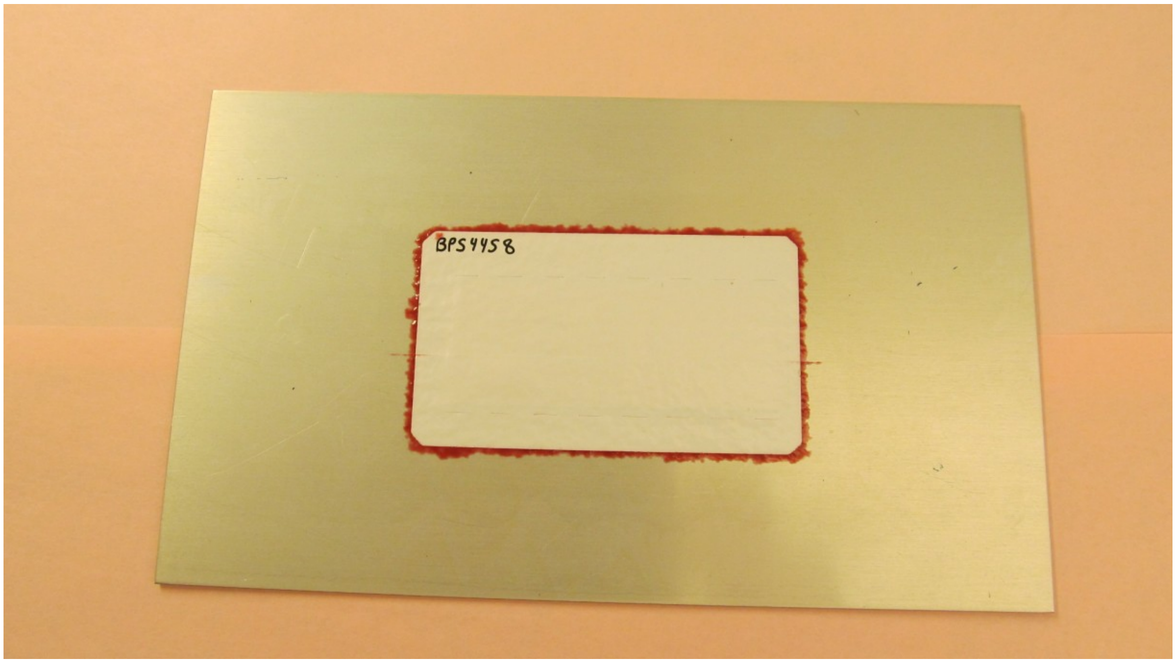


Figure 5-8 – Metal coupon (BPS 4458)

Figure 5-9 – Glass fibre/epoxy coupon (BPS 4437)

Figure 5-10 – Carbon fibre/Epoxy coupon (BPS 4511)

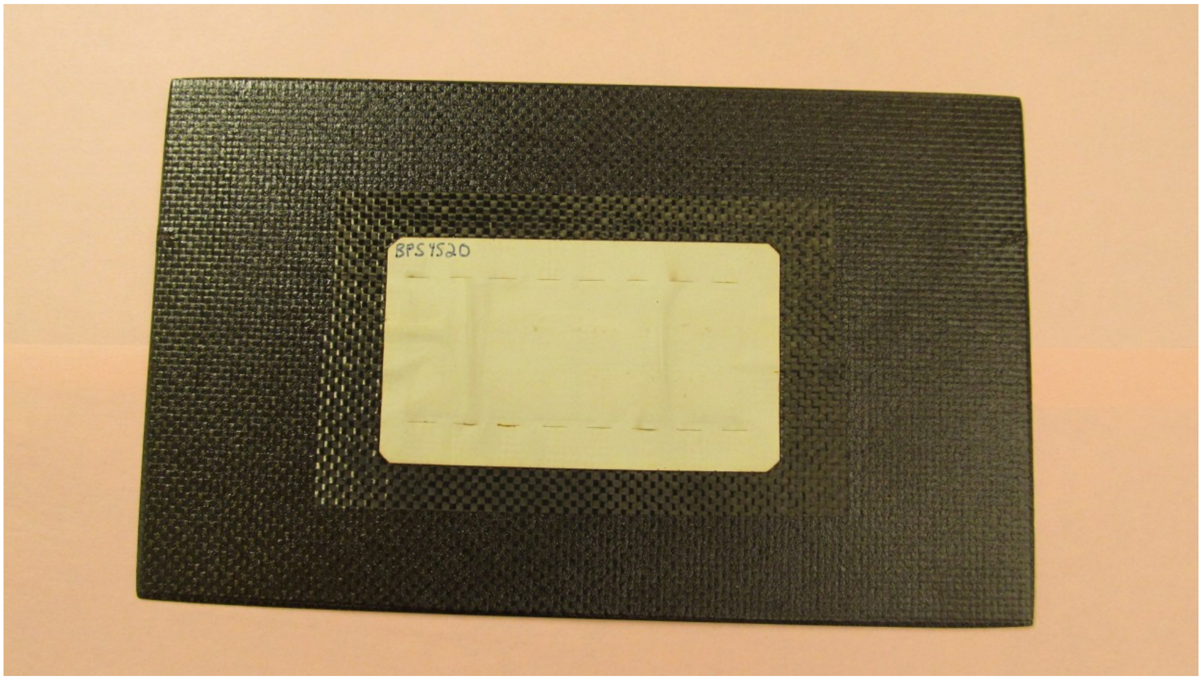


Figure 5-11 – Carbon fibre/BMI coupon (BPS 4520)

Figure 5-12 : Carbon fibre/BMI (BPS 4520) vs. Carbon fibre/Epoxy coupon (BPS 4511)

Figure 5-13 – Carbon fibre/Epoxy (BPS 4511) vs. Glass fibre/Epoxy coupon (BPS 4437)

These test panels were then sent to the RFID label manufacturer for precise read-range testing in their anechoic chamber. The results of this testing are shown graphically in Figure 5-14. In the manufacturer's anechoic chamber the apparatus automatically calculates the read-range at 21 reference frequencies between 860 and 960 MHz in precise incremental steps of 5 MHz.

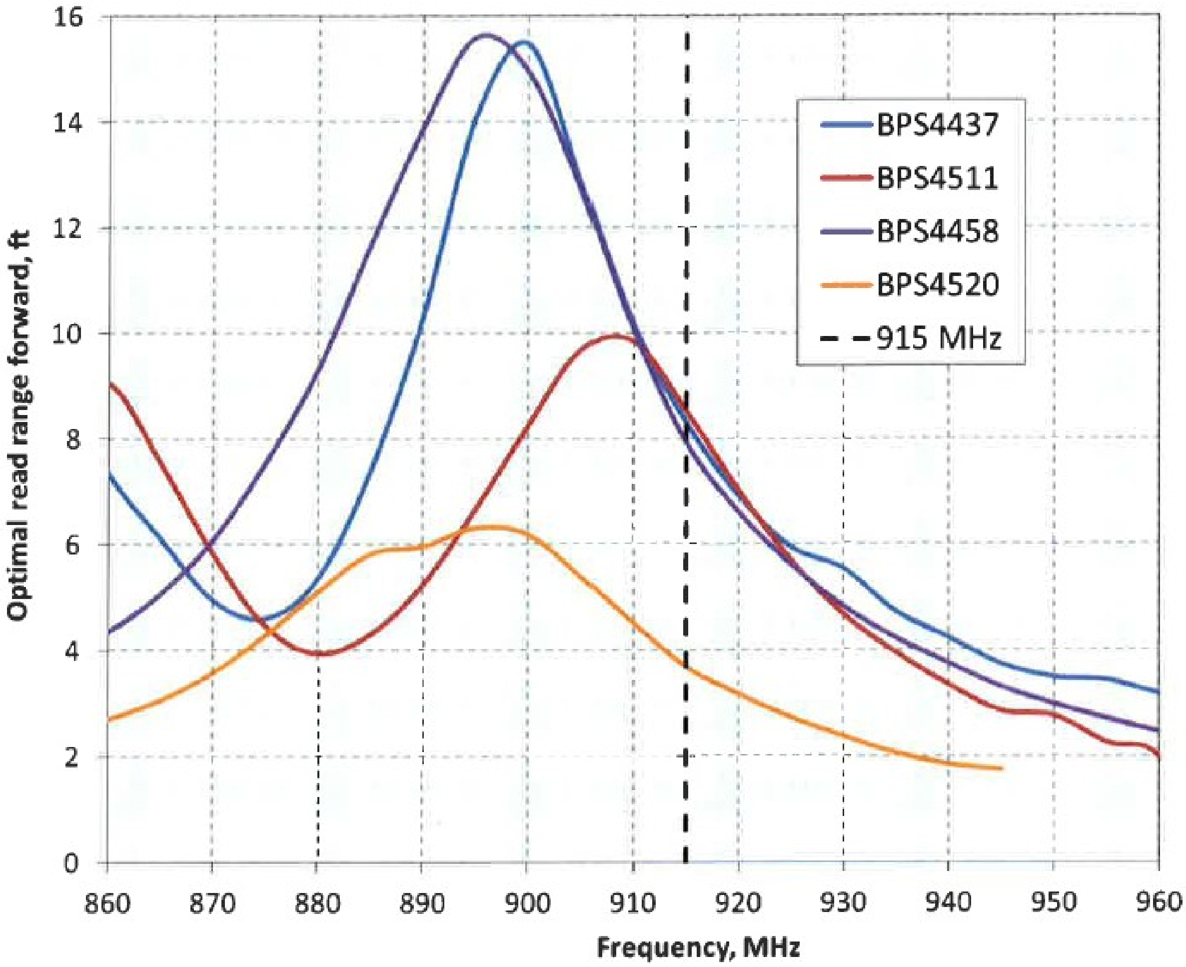


Figure 5-14 – Anechoic Chamber Test Results (Graphic courtesy of RFID Label Supplier)

The RFID frequency for North America (i.e. 915 MHz) is shown for reference [Note: the corresponding European and Japanese frequencies are: 860 MHz and 960 MHz.]

These test results indicate that for the label attached to metal (BPS 4458), glass fibre (BPS 4437) and carbon-fibre/epoxy (BPS4511) the read-range is very satisfactory at 8 feet and even though the range of the label when attached to the carbon-fibre/BMI is lower, slightly below 4 feet, it is nevertheless quite acceptable. However a comparison of the physical appearance of the labels on the different panels (Figures 5-12 & 5-13) showed that the appearance of the carbon-fibre/BMI coupon (lower part of Figure 5-12) is inferior when compared to the label attached to the other non-BMI panels. Specifically the label appears to be discoloured: if the label had printed matter on it then it would likely still be readable but its appearance is certainly not as good as before and has more pronounced "matte" finish than the labels that have been cured with the metal, glass-fibre or carbon-epoxy panels. This is not surprising given that the process conditions (autoclave pressure and temperature) of the BMI panel are markedly higher than the other materials and the BMI panel is also subjected, after autoclave curing, to a second oven process at elevated temperature for a protracted period during its manufacture. Closer examination, after its free-standing oven cure, (Figure 5-15) shows that the label had begun to delaminate, as evidenced by the peeling of the top layer around the periphery (See Figure 5-16), and is therefore not considered satisfactory for use on a real-life production part.

Figure 5-15 – Carbon fibre/BMI (BPS 4520) Panel: Label Delamination

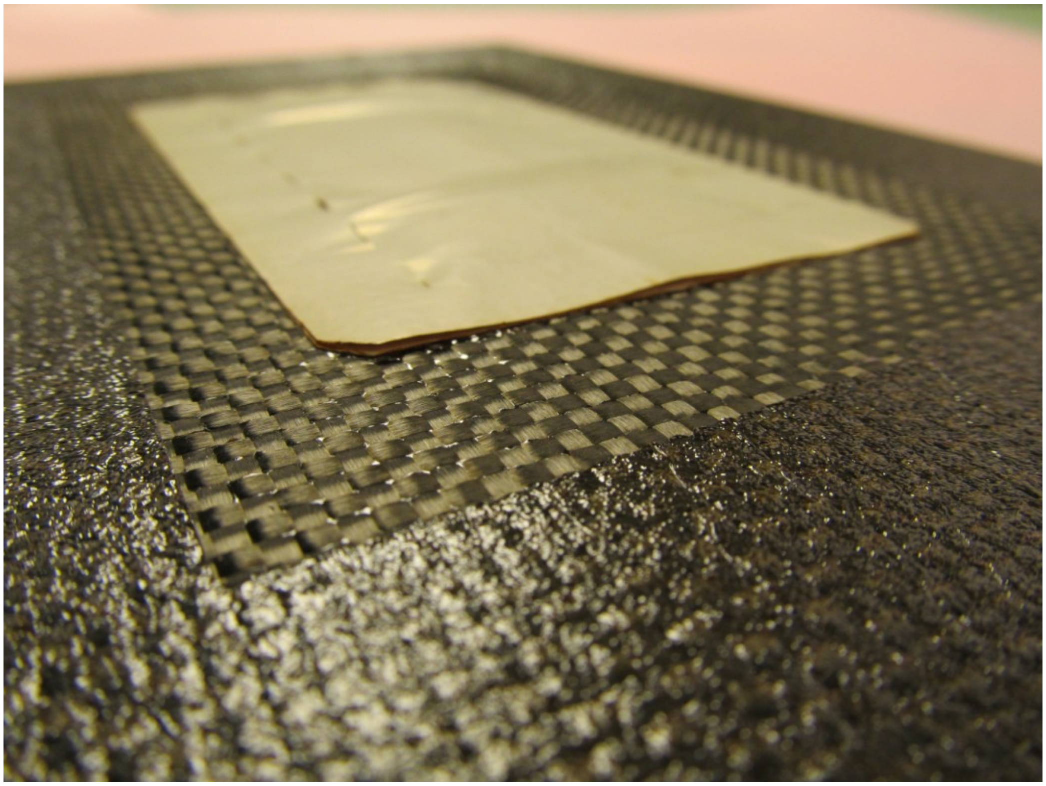


Figure 5-16 – Carbon fibre/BMI (BPS 4520) Panel: Label Corner Peeling

5.5 Summary of the Initial (February 2014) Testing

Based upon the foregoing experimental results the RFID labels, from the author's standpoint, the subject RFID label was satisfactory in terms of read-range performance on the subject labels (though clearly better in three out of the four cases) but aesthetically it was unacceptable in the case of the carbon-fibre BMI panel. Consequently the author requested that the label manufacturer investigate the use of a higher grade label material to offer improved temperature degradation resistance than the prototype tested. The manufacturer responded by stating that it believed it could solve these problems of the sample labels delaminating in the high temperature post-cure phase by using an alternate, higher temperature material. The manufacturer prepared further samples and these were made available for test in July of 2014.

5.6 Test Results for the Second Phase of Label Testing (July 2014)

Based upon the results of the first phase of testing which the author provided, the label manufacturer was quickly able to propose an upgrade to the label materials which, based on preliminary testing carried out at their facility, they believed solved the delamination problem in the post-autoclave cure oven process by using an alternate, higher temperature capability material. This testing at the label manufacturer was rudimentary since they cannot fully reproduce the harsh autoclave and oven pressures and temperatures to which the parts are exposed during part manufacturing at Bell Helicopter.

The manufacturer prepared a further four prototype samples and these were made available for test at Bell Helicopter in July of 2014. Figure 5-17 shows an example of one of the four identical RFID labels supplied to the author. The figure shows the improved label (left side) in comparison to one of the prior prototypes (right side): it is clear that the surface finish of the improved label is more glossy than the previous version, and the vent holes present in the outer cover of the previous samples are no longer present in the improved sample made from high temperature resistance material: these slots were removed at the request of the author since it is believed that, in any subsequent productionized version used in service, these slots would enable contaminants to enter into the interior of the label and harm the RFID inlay, as well as the label material itself.

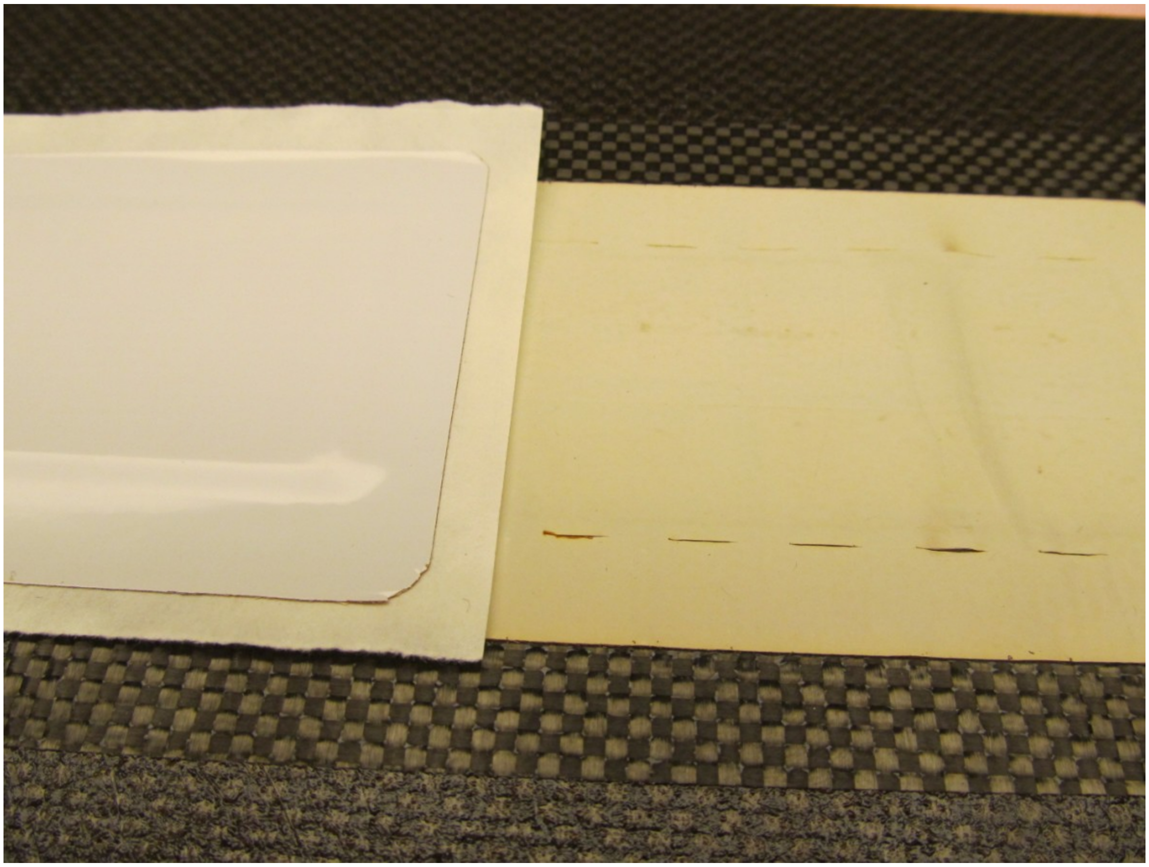


Figure 5-17 – Comparison of Improved Prototype (Left) vs. Original Prototype (Right)

One of the sample RFID labels was used to prepare a test coupon made from carbon fibre/BMI again respecting the geometry shown in Figure 5-4. Once again the build-up of the test article was as shown in cross section in Figure 5-7, and comprised (from the material coupon upwards):

- Material coupon: base layer of carbon fibre/BMI
- RFID label
- Silicon adhesive tape (Airtech-Flashbreaker 2) to be applied over the RFID label (extending 0.5 inch beyond the label)

The tests were carried out on only one of the test coupons: that of the carbon fibre/BMI. In view of the foregoing testing described in Section 6-3 this was regarded as the most severe test case. The results of the testing on this test coupon are shown in Figures 5-18 through 5-22. These photographs show that, cosmetically, the label does darken in colour as a result of exposure to the autoclave and oven exposure but nevertheless retains a satisfactory appearance and surface finish: any printing on the label would still be clearly man-readable with this colour of background. As can clearly still be seen in the Figures 5-18 through 5-22 the delamination present on the previous version has been successfully eliminated on this improved prototype version.

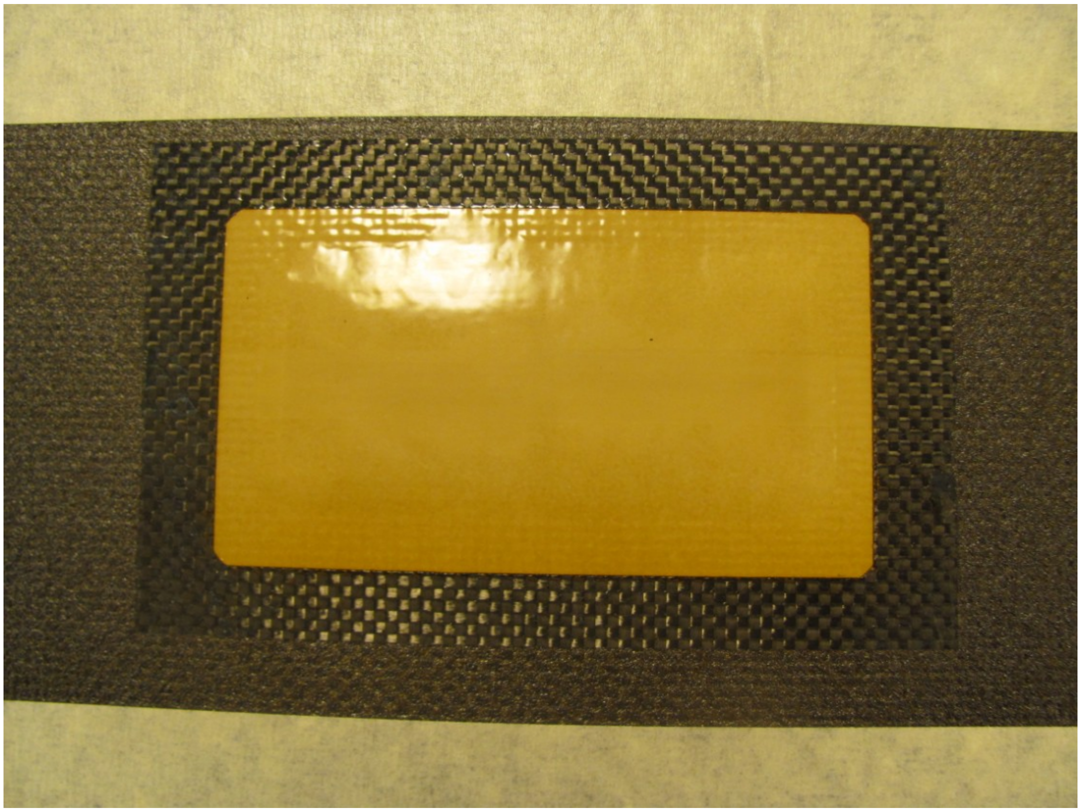


Figure 5-18 – Carbon fibre/BMI coupon (Improved Prototype)

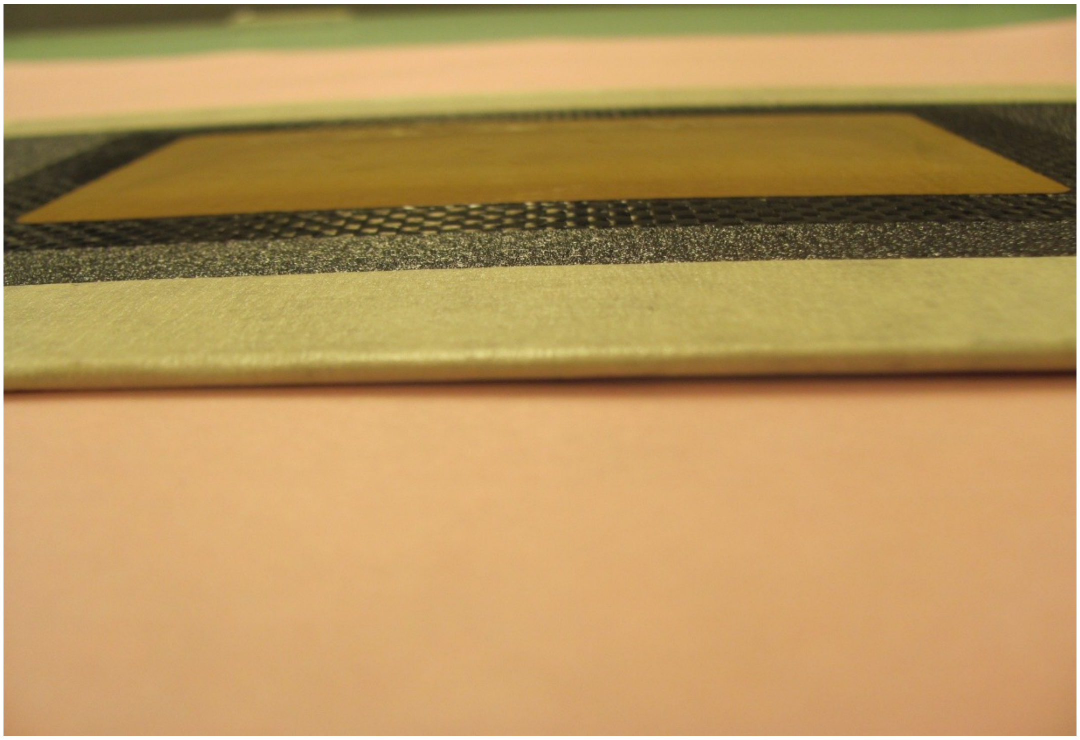


Figure 5-19 – Carbon fibre/BMI coupon (Improved Prototype)

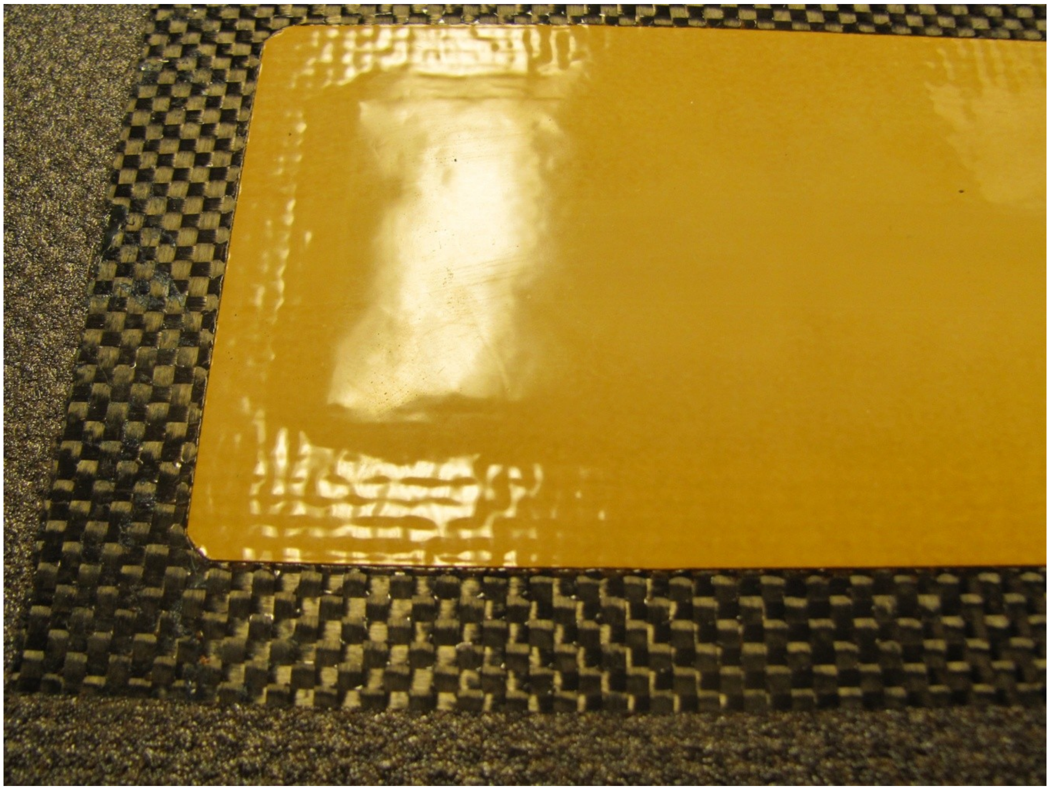


Figure 5-20 – Carbon fibre/BMI coupon (Improved Prototype)

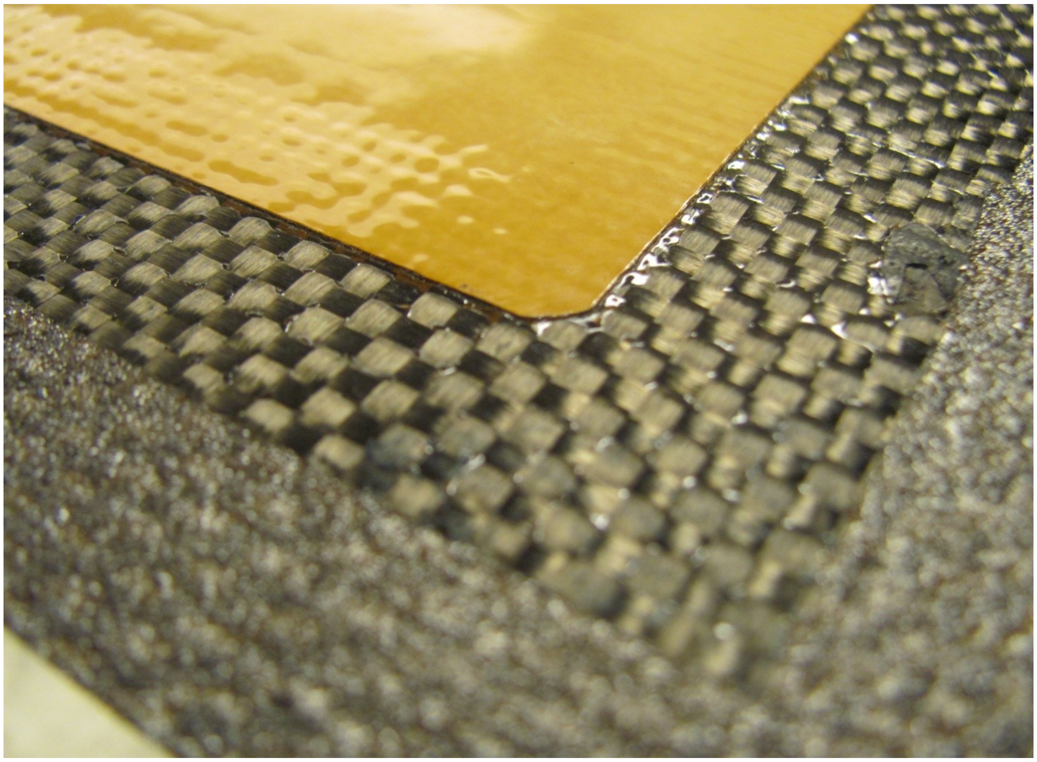


Figure 5-21 – Carbon fibre/BMI coupon (Improved Prototype)

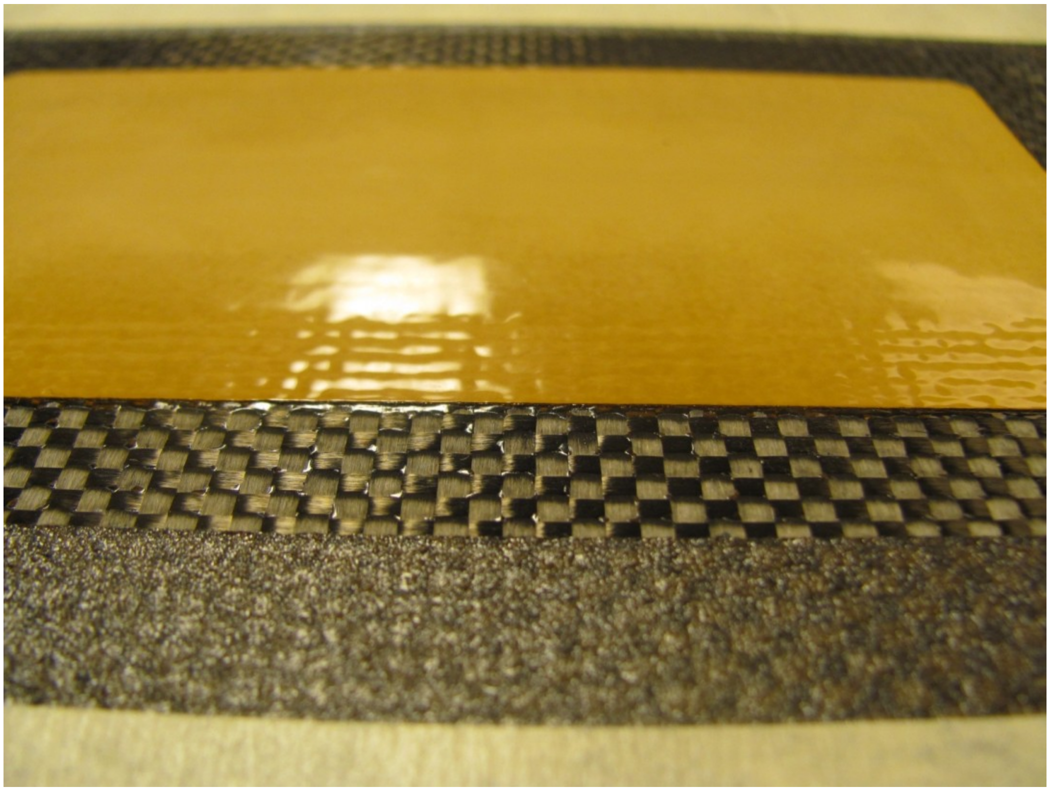


Figure 5-22 – Carbon fibre/BMI coupon (Improved Prototype)

5.7 Readability Test Results

Readability tests were carried out on this test coupon in the Concordia Lab: the test coupon gave positive survivability results (i.e. positive RFID tag read results).

This test panel was then sent to the RFID label manufacturer for precise read-range testing in their anechoic chamber. Unfortunately, although the finished RFID tag applied to Carbon BMI could also be read by the manufacturer by means of a hand-held reader (and therefore confirmed the positive result of the Concordia survivability test) it could not be read in the anechoic chamber due to the fact that the chamber's instrumentation is not capable of registering a read range of less than 2 feet. The new, improved, material certainly improves the robustness of the label, but at the expense of a reduced read-range.

The conclusion from these tests is that an RFID label that survives the harsh process temperatures of the composite bonded panel manufacturing process is achievable however further development work remains to be done to optimize the current RFID inlay to give an acceptable read-range when combined with the enhanced robust label construction used in the second prototype.

CHAPTER 6 – CONCLUSIONS & FUTURE WORK

6.1 Summary of Research

As set out in Section 3.3 this research study aimed to develop, using the 6-Sigma methodology, a representative modelling framework (using discrete-event simulation modelling techniques) for the end-of-service-life helicopter disassembly process to permit the technical impact and the ROI business case of alternative enabling RFID reverse logistics technologies to be evaluated.

During the course of this research, and as a result of the 6-Sigma approach adopted, the research scope was broadened to include an empirical aspect: the evaluation in harsh environments of the read-range performance of low-cost/low-weight RFID labels for structural parts.

This research has now been completed and the results are presented in this thesis, specifically in Chapters 4 and 5 (the chapters respectively presenting the results of the simulation and empirical (practical implementation) tag testing). The sections below present the conclusions which have been drawn from the subject research and the recommendations for further work which are proposed, based upon this work.

6.2 Research Contributions & Conclusions

As a result of carrying out this research the following conclusions can be drawn:

1. A discrete-event simulation model (using Arena software) can be created for the framework of an aircraft components' reverse logistic process: specifically that of a substantial real-life helicopter upgrade (i.e. remanufacturing) process. This simulation model framework presented in this study has shown that certain RFID technology implementation scenarios can have a beneficial impact on an RL process such as a helicopter upgrade.
2. Based upon analysis of the discrete-event simulation model findings, the four broad (progressively more sophisticated) RFID implementation scenarios assessed by this study can be ranked in the following order in terms of their impact on reducing the cycle time of the RL process:
    i. Lifed-component tagging (Most impactful)
    ii. Serialized LRU – Electrical/Avionic components
    iii. Serialized LRU – Mechanical components
    iv. Structural components (Least impactful)
3. Taking due account of the foregoing beneficial impact levels of the various RFID implementations, there is a justifiable business case (ROI) in an end-of-service-life context for the adoption of the hybrid scenario comprising "Lifed-component tagging" in combination with tagging of serialized electrical/avionic LRU components (the most impactful scenarios described above) in an RL (upgrade/remanufacturing) application, *subject to some further development of suitable lifed part tag technology.*

4. Including the remaining RFID implementation scenarios (i.e. tagging serialized mechanical, and RFID-labeling of structural components) diminishes the justifiable ROI business case for their adoption in an end-of-service-life context alone.
5. From the study's empirical work, a viable low-cost/low-weight RFID label has been refined and demonstrated to withstand harsh environments to a TRL level of 4 (i.e. basic prototype validated in a laboratory environment). Such an RFID label would be a viable replacement for existing part label technology (such as bar coding), subject to some further specific development. The RFID label technology developed during this study is capable of surviving in the very harsh environments associated with a structural part's manufacture for metal bonded and composite parts (i.e. glass fibre, carbon fibre-epoxy, and carbon fibre-BMI parts)
6. The read-range performance of the improved RFID label requires further development to reach a level suitable for in-service implementation.

6.3 Recommendations & Future Work

Based upon the conclusions derived from the simulation and empirical aspects of the research undertaken (described in the previous section), future work is required to be undertaken in order to fully realize the technical and business potential of RFID technology in a reverse logistics context. The study's conclusions have also shown that for certain classes of components the business and technical potential of the RFID technology can only be fully realized by assessing its role in other additional areas of the product life cycle (forward logistics). Taking these aspects into account the following future work is proposed as a consequence of the research presented in this study:

1. Given the conclusion that lifed components should be tagged on future helicopter platforms, there is a need to develop the data protocol of the tag memory for lifed components in general;
2. Carry out research and development activity to determine how RFID technology can be reliably used for (and possibly embodied into) lifed components of smaller size;
3. By expanding the existing simulation modelling framework, explore the technical rationale (and evaluate the business case/ROI) for applying RFID technology to all the component tagging scenarios considered in this study (i.e. lifed components, LRUs and structural parts) in the wider context of applying RFID technology to assets throughout the various phases of the product life cycle (i.e. from original vehicle manufacture, through MRO activity in service, and finally to end-of-service-life retirement or upgrade (remanufacture));
4. Explore the potential for further development of the low-cost/low-weight RFID labels developed as part of this study to further assess their long-term robustness to the in-service environment;
5. Explore the potential for improving the read-range and further reducing the size of the low-cost/low-weight RFID labels developed as part of this study.

Based on the research gaps identified and the recommendations made Bell Helicopter and CIISE have embarked on further preliminary discussions with regard to a collaborative research effort on RFID technology, commencing in the 2016 timeframe, which could be used as a basis for addressing some of these research gaps and the recommendations identified above.

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APPENDIX ONE

Examples of the Detailed Process Planning Steps Within The Major Process Steps

Stage 1: Structural/Mechanical Systems Teardown

DIS-ASSEMBLY TASK #	TASK NAME	Remove	Label Part	**Lower (x0.95)**	ESTIMATED TIME (MINS)	**Upper (x1.1)**
0	Defuel the aircraft			125.4	132	145.2
1	Remove landing gear assy and install a/c on wheeled support	Y		41.8	44	48.4
			Y	3.8	4	4.4
2	Remove and inspect MR hub and blade assy	Y		57	60	66
			Y	5.7	6	6.6
3	Remove and inspect RED MR blade	Y		28.5	30	33
			Y	2.85	3	3.3
4	Remove and inspect WHITE MR blade	Y		28.5	30	33
			Y	2.85	3	3.3
5	Remove aircraft ID plate	Y		9.5	10	11
			Y	0.95	1	1.1
6	Remove servo cowling	Y		5.7	6	6.6
			Y	0.95	1	1.1
7	Remove XMSN cowling	Y		5.7	6	6.6
			Y	0.95	1	1.1
8	Remove air management cowling	Y		19.95	21	23.1
			Y	0.95	1	1.1
9	Remove engine cowling	Y		9.5	10	11
			Y	0.95	1	1.1
10	Remove oil cooler cowling	Y		5.7	6	6.6
			Y	0.95	1	1.1
11	Remove TR driveshaft cowling	Y		5.7	6	6.6
			Y	0.95	1	1.1
12	Remove upper TR gearbox cowling	Y		5.7	6	6.6
			Y	0.95	1	1.1
13	Remove lower TR gearbox cowling	Y		5.7	6	6.6
			Y	0.95	1	1.1
14	Remove pilot door RH	Y		5.7	6	6.6
			Y	0.95	1	1.1
15	Remove pilot door LH	Y		5.7	6	6.6
			Y	0.95	1	1.1
16	Remove RH aft door	Y		5.7	6	6.6
			Y	0.95	1	1.1
17	Remove LH aft door	Y		5.7	6	6.6
			Y	0.95	1	1.1
18	Remove litter door	Y		5.7	6	6.6
			Y	0.95	1	1.1
19	Remove cargo baggage door	Y		5.7	6	6.6
			Y	0.95	1	1.1
20	Remove LH chin bubble	Y		62.7	66	72.6
			Y	0.95	1	1.1

21	Remove RH chin bubble	Y		62.7	66	72.6
			Y	0.95	1	1.1
22	Remove tailboom access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
23	Remove fuel shutoff access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
24	Remove landing light access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
25	Remove fuel boost pump access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
26	Remove vertical fin	Y		9.5	10	11
			Y	0.95	1	1.1
27	Remove horizontal stabilizer assy	Y		62.7	66	72.6
			Y	0.95	1	1.1
28	Remove aft short shaft	Y		9.5	10	11
			Y	0.95	1	1.1
29	Remove TR hub and blade assy	Y		30.4	32	35.2
			Y	0.95	1	1.1
30	Remove tailboom	Y		47.5	50	55
			Y	0.95	1	1.1
31	Remove #1 TR driveshaft assy	Y		9.5	10	11
			Y	0.95	1	1.1
32	Remove #2 TR driveshaft assy	Y		9.5	10	11
			Y	0.95	1	1.1
33	Remove #3 TR driveshaft assy	Y		9.5	10	11
			Y	0.95	1	1.1
34	Remove #4 TR driveshaft assy	Y		9.5	10	11
			Y	0.95	1	1.1
35	Remove #5 TR driveshaft assy	Y		9.5	10	11
			Y	0.95	1	1.1
36	Remove TR gearbox assy	Y		47.5	50	55
			Y	0.95	1	1.1
37	Remove stretcher assy	Y		31.35	33	36.3
			Y	0.95	1	1.1
38	Remove kick shield_pilot organizer assy	Y		5.7	6	6.6
			Y	0.95	1	1.1
39	Remove aft seat assemblies	Y		15.2	16	17.6
			Y	0.95	1	1.1
40	Remove all floor protectors	Y		5.7	6	6.6
			Y	0.95	1	1.1
41	Install protective rubber floor mats	Y		15.2	16	17.6
			Y	0.95	1	1.1
42	Remove oxygen system in cargo_baggage area	Y		30.4	32	35.2
			Y	0.95	1	1.1
43	Remove medical probe	Y		19.95	21	23.1
			Y	0.95	1	1.1
44	Remove MRL mount	Y		5.7	6	6.6
			Y	0.95	1	1.1
45	Remove med bar	Y		5.7	6	6.6
			Y	0.95	1	1.1
46	Remove sharps container and narcs box	Y		5.7	6	6.6
			Y	0.95	1	1.1
47	Remove portable oxygen mount	Y		19.95	21	23.1
			Y	0.95	1	1.1
48	Remove aft interior trim passenger overhead	Y		19.95	21	23.1
			Y	0.95	1	1.1
49	Remove hat rack	Y		9.5	10	11
			Y	0.95	1	1.1

50	Remove aft seat belts	Y		19.95	21	23.1
			Y	0.95	1	1.1
51	Remove box beam access panel_6 each	Y		19.95	21	23.1
			Y	0.95	1	1.1
52	Remove aft facing center seat access panel	Y		9.5	10	11
			Y	0.95	1	1.1
53	Remove fume access panel	Y		9.5	10	11
			Y	0.95	1	1.1
54	Remove vertical tunnel access panel	Y		15.2	16	17.6
			Y	0.95	1	1.1
55	Remove roll-over accces panel_STA 150_4 each	Y		15.2	16	17.6
			Y	0.95	1	1.1
56	Remove cargo compartment sidewall access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
57	Remove cargo compartment aft access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
58	Remove cargo compartment OH access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
59	Remove FWD interior OH trim	Y		15.2	16	17.6
			Y	0.95	1	1.1
60	Remove FWD interior trim center fairing	Y		9.5	10	11
			Y	0.95	1	1.1
61	Remove FWD seat belts and pilot headrest	Y		9.5	10	11
			Y	0.95	1	1.1
62	Remove fire extinguisher and bracket	Y		5.7	6	6.6
			Y	0.95	1	1.1
63	Remove LH and RH seat pans	Y		9.5	10	11
			Y	0.95	1	1.1
64	Remove collective closeout access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
65	Remove instrument access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
66	Remove instrument shroud	Y		5.7	6	6.6
			Y	0.95	1	1.1
67	Remove LH and RH pedestal access panel	Y		5.7	6	6.6
			Y	0.95	1	1.1
68	Remove LH and RH crush panel guards	Y		5.7	6	6.6
			Y	0.95	1	1.1
69	Remove battery with history card attached	Y		5.7	6	6.6
			Y	0.95	1	1.1
70	Remove ballast	Y		19.95	21	23.1
			Y	0.95	1	1.1
71	Remove lower wire strike	Y		19.95	21	23.1
			Y	0.95	1	1.1
72	Remove 2 each PC links	Y		9.5	10	11
			Y	0.95	1	1.1
73	Remove LH_RH cyclic control tubes from Hyd servos to XMSN	Y		15.2	16	17.6
			Y	0.95	1	1.1
74	Remove collective control tube from hyd servo to XMSN	Y		5.7	6	6.6
			Y	0.95	1	1.1
75	Remove hydraulic pump and tach gen assy	Y		19.95	21	23.1
			Y	0.95	1	1.1
76	Remove swash plate assy	Y		30.4	32	35.2
			Y	0.95	1	1.1
77	Remove XMSN support links	Y		15.2	16	17.6
			Y	0.95	1	1.1
78	Remove XMSN assy	Y		40.85	43	47.3
			Y	0.95	1	1.1

79	Remove swash plate drive link assy	Y		5.7	6	6.6
			Y	0.95	1	1.1
80	Remove mast assy	Y		19.95	21	23.1
			Y	0.95	1	1.1
81	Remove LH_RH nodel beam assemblies	Y		61.75	65	71.5
			Y	0.95	1	1.1
82	Remove hydraulic reservoir	Y		19.95	21	23.1
			Y	0.95	1	1.1
83	Remove hydraulic solenoid and relief valve	Y		19.95	21	23.1
			Y	0.95	1	1.1
84	Remove hydraulic filters	Y		19.95	21	23.1
			Y	0.95	1	1.1
85	Remove hydraulic hard lines	Y		30.4	32	35.2
			Y	0.95	1	1.1
86	Remove FWD short shaft	Y		15.2	16	17.6
			Y	0.95	1	1.1
87	Remove droop compensator system	Y		19.95	21	23.1
			Y	0.95	1	1.1
88	Remove engine assembly	Y		376.2	396	435.6
			Y	0.95	1	1.1
89	Remove engine LH_RH mounting trunnions_Place on stand	Y		15.2	16	17.6
			Y	0.95	1	1.1
90	Remove main driveshaft assembly	Y		40.85	43	47.3
			Y	0.95	1	1.1
91	Remove rotor brake calipers_2_and brake disc	Y		30.4	32	35.2
			Y	0.95	1	1.1
92	Remove freewheeling assy	Y		95	100	110
			Y	0.95	1	1.1
93	Remove starter generator and SG mounting pad	Y		30.4	32	35.2
			Y	0.95	1	1.1
94	Remove engine exhaust duct	Y		19.95	21	23.1
			Y	0.95	1	1.1
95	Remove engine bellmouth assembly	Y		47.5	50	55
			Y	0.95	1	1.1
96	Remove LH_RH tach generator	Y		19.95	21	23.1
			Y	0.95	1	1.1
97	Remove engine heater fitting	Y		30.4	32	35.2
			Y	0.95	1	1.1
98	Remove engine bleed air fitting and hose	Y		15.2	16	17.6
			Y	0.95	1	1.1
99	Remove governor control arm	Y		5.7	6	6.6
			Y	0.95	1	1.1
100	Remove engine mount legs_6	Y		19.95	21	23.1
			Y	0.95	1	1.1
101	Remove oil tank assembly	Y		61.75	65	71.5
			Y	0.95	1	1.1
102	Remove oil cooler blower assembly	Y		46.55	49	53.9
			Y	0.95	1	1.1
103	Remove anti-torque system	Y		61.75	65	71.5
			Y	0.95	1	1.1
104	Remove elevator control system	Y		109.25	115	126.5
			Y	0.95	1	1.1
105	Remove cyclic control system	Y		61.75	65	71.5
			Y	0.95	1	1.1
106	Remove collective control system	Y		93.1	98	107.8
			Y	0.95	1	1.1
107	Remove instrument lines	Y		124.45	131	144.1
			Y	0.95	1	1.1

108	Remove heater system	Y		375.25	395	434.5
			Y	0.95	1	1.1
109	Remove servo rack assembly	Y		61.75	65	71.5
			Y	0.95	1	1.1
110	Remove pylon supports_4	Y		30.4	32	35.2
			Y	0.95	1	1.1
111	Remove XMSN isolation support	Y		61.75	65	71.5
			Y	0.95	1	1.1
112	Remove LH_RH drag pins	Y		19.95	21	23.1
			Y	0.95	1	1.1
113	Remove gas producer system	Y		61.75	65	71.5
			Y	0.95	1	1.1
114	Remove LH FWD fuel cell assembly	Y		93.1	98	107.8
			Y	0.95	1	1.1
115	Remove RH FWD fuel cell assembly	Y		93.1	98	107.8
			Y	0.95	1	1.1
116	Remove aft fuel cell assembly	Y		187.15	197	216.7
			Y	0.95	1	1.1
117	Remove fuel system plumbing between fuel cells	Y		61.75	65	71.5
			Y	0.95	1	1.1
118	Remove fuel vent system	Y		124.45	131	144.1
			Y	0.95	1	1.1
119	Remove fuel supply to engine compartment	Y		61.75	65	71.5
			Y	0.95	1	1.1
120	Remove air conditioning system	Y		187.15	197	216.7
			Y	0.95	1	1.1
121	Remove oxygen system equipment	Y		19.95	21	23.1
			Y	0.95	1	1.1
122	Remove medical system equipment	Y		94.05	99	108.9
			Y	0.95	1	1.1
123	Remove flexure arm assembly_2	Y		30.4	32	35.2
			Y	0.95	1	1.1

Stage 2: Avionice/Electrical Teardown

DIS-ASSEMBLY TASK #	TASK NAME	Remove / Instal	Label / Record Findings	Lower (x0.95)	ESTIMATED TIME (MINS)	Upper (x1.1)
1	Remove and inspect airconditioning system (See Part 2A) *					
2	Remove and inspect the Intellistart system	Y		38	40	44
			Y	4.75	5	5.5
3	Remove and inspect the instrument panel assembly	Y		47.5	50	55
			Y	11.4	12	13.2
4	Remove and inspect the pitot-static system	Y		41.8	44	48.4
			Y	0.95	1	1.1
5	Remove and inspect the pitot tube connector	Y		22.8	24	26.4
			Y	0.95	1	1.1
6	Remove and inspect the LH fuel boost pump circuit breaker	Y		3.8	4	4.4
			Y	0.95	1	1.1
7	Remove and inspect the battery relay	Y		8.55	9	9.9
			Y	0.95	1	1.1
8	Remove and inspect the enternal power relay	Y		8.55	9	9.9
			Y	0.95	1	1.1
9	Remove and inspect the external power receptacle	Y		8.55	9	9.9
			Y	0.95	1	1.1
10	Remove and inspect all main busbar cables	Y		9.5	10	11
			Y	6.65	7	7.7
11	Remove and inspect compass	Y		3.8	4	4.4
			Y	0.95	1	1.1
12	Remove and inspect terminal block	Y		8.55	9	9.9
			Y	0.95	1	1.1
13	Remove and inspect light dimming relay	Y		8.55	9	9.9
			Y	0.95	1	1.1
14	Remove and inspect XMSN oil pressure switch	Y		8.55	9	9.9
			Y	0.95	1	1.1
15	Remove and inspect pilot AUX control panel (4 parts)	Y		9.5	10	11
			Y	3.8	4	4.4
16	Remove and inspect lighting resistor	Y		3.8	4	4.4
			Y	0.95	1	1.1
17	Remove and inspect 5V power supply	Y		3.8	4	4.4
			Y	0.95	1	1.1
18	Remove and inspect light dimming relay resistor and diode (2 parts)	Y		3.8	4	4.4
			Y	1.9	2	2.2
19	Remove and inspect lighting transistor	Y		3.8	4	4.4
			Y	0.95	1	1.1
20	Remove and inspect terminal block 8TB1	Y		3.8	4	4.4
			Y	0.95	1	1.1
21	Remove and inspect 5V DC lighting blocks (2 parts)	Y		3.8	4	4.4
			Y	1.9	2	2.2
22	Remove and inspect landing light relays (2 parts)	Y		7.6	8	8.8
			Y	1.9	2	2.2
23	Remove and inspect landing lights (2 parts)	Y		17.1	18	19.8
			Y	1.9	2	2.2
24	Remove and inspect engine RPM resistor	Y		8.55	9	9.9
			Y	0.95	1	1.1
25	Remove and inspect warning horn mute relays (2 parts)	Y		7.6	8	8.8
			Y	1.9	2	2.2
26	Remove and inspect low rotor RPM sensor connector	Y		8.55	9	9.9
			Y	0.95	1	1.1
27	Remove and inspect fuel valve switch	Y		8.55	9	9.9
			Y	0.95	1	1.1
28	Remove and inspect warning horn mute switch	Y		8.55	9	9.9
			Y	0.95	1	1.1
29	Remove and inspect fuel forward total switch	Y		8.55	9	9.9
			Y	0.95	1	1.1
30	Remove and inspect terminal block 4TBA	Y		3.8	4	4.4
			Y	0.95	1	1.1
31	Remove and inspect map light	Y		3.8	4	4.4
			Y	0.95	1	1.1
32	Remove and inspect collective switches (4 parts)	Y		4.75	5	5.5
			Y	3.8	4	4.4
33	Remove and inspect RH position light	Y		8.55	9	9.9
			Y	0.95	1	1.1
34	Remove and inspect LH position light	Y		8.55	9	9.9
			Y	0.95	1	1.1
35	Remove and inspect litter door switches (2 parts)	Y		7.6	8	8.8
			Y	1.9	2	2.2
36	Remove and inspect airspeed limitations panel	Y		3.8	4	4.4

32	Remove and inspect collective switches (4 parts)	Y		4.75	5	5.5
			Y	3.8	4	4.4
33	Remove and inspect RH position light	Y		8.55	9	9.9
			Y	0.95	1	1.1
34	Remove and inspect LH position light	Y		8.55	9	9.9
			Y	0.95	1	1.1
35	Remove and inspect litter door switches (2 parts)	Y		7.6	8	8.8
			Y	1.9	2	2.2
36	Remove and inspect airspeed limitations panel	Y		3.8	4	4.4
			Y	0.95	1	1.1
37	Remove and inspect airspeed circuit breaker panel	Y		8.55	9	9.9
			Y	0.95	1	1.1
38	Remove and inspect XMSN bulkhead connector	Y		8.55	9	9.9
			Y	0.95	1	1.1
39	Remove and inspect engine out warning horn	Y		8.55	9	9.9
			Y	0.95	1	1.1
40	Remove and inspect low rotor warning horn	Y		8.55	9	9.9
			Y	0.95	1	1.1
41	Remove and inspect cabin lights	Y		19	20	22
			Y	3.8	4	4.4
42	Remove and inspect voltage regulator	Y		7.6	8	8.8
	Record P/N & S/N		Y	1.9	2	2.2
43	Remove and inspect engine bulkhead connector	Y		8.55	9	9.9
			Y	0.95	1	1.1
44	Remove and inspect aft relay panel (6 parts)	Y		19	20	22
			Y	5.7	6	6.6
45	Remove and inspect baggage door switch	Y		8.55	9	9.9
			Y	0.95	1	1.1
46	Remove and inspect fuel dump valve switch	Y		3.8	4	4.4
			Y	0.95	1	1.1
47	Remove and inspect tail boom connector	Y		3.8	4	4.4
			Y	0.95	1	1.1
48	Remove and inspect tail boom connector 8P2	Y		3.8	4	4.4
			Y	0.95	1	1.1
49	Remove and inspect LH rear position light	Y		8.55	9	9.9
			Y	0.95	1	1.1
50	Remove and inspect RH rear position light	Y		8.55	9	9.9
			Y	0.95	1	1.1
51	Remove and inspect terminal block	Y		3.8	4	4.4
			Y	0.95	1	1.1
52	Remove and inspect tail position light (3 parts)	Y		9.5	10	11
			Y	2.85	3	3.3
53	Remove and inspect LED anti-collision lights (4 parts)	Y		9.5	10	11
			Y	3.8	4	4.4

Stage 3: Structural Airframe Inspections

DIS-ASSEMBLY TASK #	TASK NAME	Inspect	Record Data	Lower (x0.95)	ESTIMATED TIME (MINS)	Upper (x1.1)
1	Inspect roof panel for separation and corrosion	Y		114	120	132
			Y	11.4	12	13.2
2	Inspect roof panel for properly installed fasteners and condition	Y		57	60	66
			Y	5.7	6	6.6
3	Inspect roof panel for cracks, corrosion and condition	Y		57	60	66
			Y	5.7	6	6.6
4	Inspect XMSN cowling Dzus rails for worn receptacles, chafing, cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
5	Inspect all engine mounts, clips, channels for corrosion and cracks	Y		28.5	30	33
			Y	2.85	3	3.3
7	Inspect all engine cowl latch stops for wear and condition	Y		9.5	10	11
			Y	0.95	1	1.1
8	Inspect engine cowl door support rods for wear and condition	Y		9.5	10	11
			Y	0.95	1	1.1
9	Inspect forward firewall, firewall receptacles and receptacle railing for cracks and general condition	Y		42.75	45	49.5
			Y	4.75	5	5.5
10	Inspect engine pan and exterior FWD mount areas for cracks, corrosion and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
11	Inspect oil cooler deck for cracks, corrosion, debonding and general condition	Y		19	20	22
			Y	1.9	2	2.2
12	Inspect oil cooler cowling Dzus rails for wear, cracks and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
13	Inspect AFT firewall, firewall receptacles and receptacle mount bracing for cracks, wear and general condition	Y		42.75	45	49.5
			Y	3.8	4	4.4
14	Inspect RH and LH nose panels and attached bracing for debonding, dents, cracks, corrosion, oversized holesfor chinbubble retainers and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
16	Inspect battery door and battery door area for fit, worn or missing seals, cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
17	Inspect Pitot tube support for cracks, corrosion and general condition	Y		4.75	5	5.5
			Y	0.95	1	1.1
18	Inspect GPU brackets and area for cracks, corrosion and general condition	Y		4.75	5	5.5
			Y	0.95	1	1.1
19	Inspect landing light mount for cracks, corrosion and general condition	Y		4.75	5	5.5
			Y	0.95	1	1.1
20	Inspect pilot and copilot window area for cracks, corrosion and oversized retainer rivet holes	Y		9.5	10	11
			Y	0.95	1	1.1
21	Inspect pilot and copilot sky light window area for cracks, corrosion and oversized retainer rivet holes	Y		9.5	10	11
			Y	0.95	1	1.1
22	Inspect RH FWD door post and frame for cracks, condition and oversized retainer rivet holes, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
23	Inspect LH FWD door post and frame for cracks, condition and oversized retainer rivet holes, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
24	Inspect RH center and AFT door post and frame for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
25	Inspect LH AFT door post and frame for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
26	Inspect battery bay floor and surrounding area for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
27	Inspect structure behind and below battery floor for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
28	Inspect center anti-torque pedals bellcrank mounts for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
29	Inspect pilot and copilot seat panel webs for cracks, corrosion and general condition	Y		9.5	10	11

30	Inspect pilot and copilot kick panels for cracks, corrosion delamination and general condition	Y		4.75	5	5.5
			Y	0.95	1	1.1
31	Inspect pilot and copilot seat panels for cracks, corrosion, delamination and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
32	Inspect pilot and copilot OH panels and surrounding area for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
33	Inspect LH and RH aft plenums and turn vanes for cracks, corrosion, brittleness and security of attachment	Y		19	20	22
			Y	1.9	2	2.2
34	Inspect console pedestal, RH and LH pedestal webs, support angles and lower deck area for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
35	Inspect upper support for the RH and LH kick panels for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
36	Inspect pilot and copilot center seat structure for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
37	Inspect copilot swing door for damage and wear	Y		4.75	5	5.5
			Y	0.95	1	1.1
38	Inspect broom closet angles and webs for cracks, corrosion, working rivets and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
39	Inspect box beam for cracks, corrosion working rivets and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
40	Inspect aft seat panel and aft seat kick panel debonding, cracks, corrosion, working rivets and general condition	Y		19	20	22
			Y	1.9	2	2.2
41	Inspect passenger compartment OH trim panel supports	Y		19	20	22
			Y	1.9	2	2.2
42	Inspect boost pump ring for debonding and security (with fuel bladder removed)	Y		9.5	10	11
			Y	0.95	1	1.1
43	Inspect aft tub for cracks, debonding, cracks, corrosion, sharp edges and general condition (with fuel bladder removed)	Y		57	60	66
			Y	5.7	6	6.6
44	Inspect the fuel cell side of the T-splice angle between the FWD and AFT lower tubs (with FWD fuel bladder removed)	Y		19	20	22
			Y	1.9	2	2.2
45	Inspect interior of RH and LH fuel cell areas for cracks, corrosion, debonding, sharp edges and general condition (with FWD fuel bladder removed)			57	60	66
				5.7	6	6.6
46	Inspect FWD fuel cell seat panels for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
47	Inspect all attaching and support angles of RH and LH fuel cell areas	Y		19	20	22
			Y	1.9	2	2.2
48	Inspect both RH and LH passenger door frames	Y		28.5	30	33
			Y	2.85	3	3.3
49	Inspect upper RH longeron for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
50	Inspect upper LH longeron for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
51	Inspect lower RH longeron for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
52	Inspect lower LH longeron for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
53	Inspect forward baggage bay wall for cracks, debonding, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
54	Inspect baggage bay floor for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
55	Inspect interior of baggage bay roof webs, roof stiffeners, compartment ribs for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
56	Inspect all RH body skins for damage, corrosion and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
57	Inspect all LH body skins for damage, corrosion and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
58	Inspect tailboom attachment fittings for corrosion, elongation and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
59	Inspect tailboom attachment bulkhead for cracks, warpage, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
60	Inspect baggage bay bulkhead for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
61	Inspect baggage bay door hinges for cracks, corrosion and general condition	Y		4.75	5	5.5
			Y	0.95	1	1.1
62	Inspect main fuselage station bulkheads and surrounding areas for cracks, corrosion and general condition	Y		57	60	66
			Y	5.7	6	6.6
63	Inspect engine pan and AFT oil coller deck supports for cracks, corrosion and general condition	Y		57	60	66
			Y	5.7	6	6.6
64	Inspect forward tub interior and exterior for debonding, cracks, corrosion and general condition	Y		57	60	66
			Y	5.7	6	6.6
65	Inspect tee angle that connects to FWD tub and AFT tub for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
66	Inspect lower aft shelf for debonding, cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
67	Inspect aft fairing for debonding, cracks, corrosion and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
68	Inspect LH forward door after removal for cracks, corrosion and general condition	Y		19	20	22

64	Inspect forward tub interior and exterior for debonding, cracks, corrosion and general condition	Y		57	60	66
			Y	5.7	6	6.6
65	Inspect tee angle that connects to FWD tub and AFT tub for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
66	Inspect lower aft shelf for debonding, cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
67	Inspect aft fairing for debonding, cracks, corrosion and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
68	Inspect LH forward door after removal for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
69	Inspect RH forward door after removal for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
70	Inspect LH aft door after removal for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
71	Inspect RH aft door after removal for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
72	Inspect LH center litter door after removal for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
73	Inspect baggage bay door after removal for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
74	Inspect oil cooler cowling for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
75	Inspect engine cowling for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
76	Inspect air management cowling for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
77	Inspect air management Dzus snow deflector kit for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
78	Inspect forward XMSN cowling for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
79	Inspect forward servo cowling for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
80	Inspect tail rotor drive shaft cowling for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
81	Inspect tail rotor cowling for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
82	Inspect landing gear_skid tubes_cross tubes_steps to manufacturer's instructions	Y		38	40	44
			Y	3.8	4	4.4
83	Inspect landing gear attachment on airframe for wear condition, corrosion and security	Y		19	20	22
			Y	1.9	2	2.2
84	Record tailboom part number_Mod number_serial number			4.75	5	5.5
				0.95	1	1.1
85	Record horizontal stab part number_Mod number_serial number			4.75	5	5.5
				0.95	1	1.1
86	Inspect upper tailboom skin for cracks, chafing, corrosion, dents and general condition	Y		19	20	22
			Y	1.9	2	2.2
87	Inspect lower tailboom skin for cracks, chafing, corrosion, dents and general condition	Y		19	20	22
			Y	1.9	2	2.2
88	Inspect all taiboom Dzus clips for cracks, corrosion, dents and general condition	Y		19	20	22
			Y	1.9	2	2.2
89	Inspect aft hanger bearing brackets for cracks, corrosion, dents and general condition	Y		19	20	22
			Y	1.9	2	2.2
90	Inspect entire tailboom's rivets for looseness	Y		28.5	30	33
			Y	2.85	3	3.3
91	Inspect vertical fin supports for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
92	Inspect tail rotor gearbox support for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
93	Inspect for upper FWD skin chafe pad repair serviceability	Y		14.25	15	16.5
			Y	0.95	1	1.1
94	Inspect horizontal stab supports for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2

74	Inspect oil cooler cowling for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
75	Inspect engine cowling for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
76	Inspect air management cowling for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
77	Inspect air management Dzus snow deflector kit for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
78	Inspect forward XMSN cowling for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
79	Inspect forward servo cowling for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
80	Inspect tail rotor drive shaft cowling for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
81	Inspect tail rotor cowling for cracks, corrosion and general condition	Y		14.25	15	16.5
			Y	0.95	1	1.1
82	Inspect landing gear_skid tubes_cross tubes_steps to manufacturer's instructions	Y		38	40	44
			Y	3.8	4	4.4
83	Inspect landing gear attachment on airframe for wear condition, corrosion and security	Y		19	20	22
			Y	1.9	2	2.2
84	Record tailboom part number_Mod number_serial number			4.75	5	5.5
				0.95	1	1.1
85	Record horizontal stab part number_Mod number_serial number			4.75	5	5.5
				0.95	1	1.1
86	Inspect upper tailboom skin for cracks, chafing, corrosion, dents and general condition	Y		19	20	22
			Y	1.9	2	2.2
87	Inspect lower tailboom skin for cracks, chafing, corrosion, dents and general condition	Y		19	20	22
			Y	1.9	2	2.2
88	Inspect all taiboom Dzus clips for cracks, corrosion, dents and general condition	Y		19	20	22
			Y	1.9	2	2.2
89	Inspect aft hanger bearing brackets for cracks, corrosion, dents and general condition	Y		19	20	22
			Y	1.9	2	2.2
90	Inspect entire tailboom's rivets for looseness	Y		28.5	30	33
			Y	2.85	3	3.3
91	Inspect vertical fin supports for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
92	Inspect tail rotor gearbox support for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
93	Inspect for upper FWD skin chafe pad repair serviceability	Y		14.25	15	16.5
			Y	0.95	1	1.1
94	Inspect horizontal stab supports for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2
95	Inspect horizontal stab for cracks, corrosion, debonding and general condition	Y		28.5	30	33
			Y	2.85	3	3.3
96	Inspect finlet Supports for cracks, corrosion, hole elongation and general condition	Y		19	20	22
			Y	1.9	2	2.2
97	Inspect RH finlet for debonding, cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
98	Inspect LH finlet for debonding, cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
99	Inspect horiz stab inserts for cracks, corrosion and condition	Y		19	20	22
			Y	1.9	2	2.2
100	Inspect max allowable wear limits on tailrotor gearbox mounting holes	Y		9.5	10	11
			Y	0.95	1	1.1
101	Inspect max allowable wear limits on vertical fin mounting holes on tailboom tail rotor gearbox canister	Y		9.5	10	11
			Y	0.95	1	1.1
102	Inspect tail rotor gearbox stud holes for required size	Y		9.5	10	11
			Y	0.95	1	1.1
103	Inspect tail rotor gearbox pin holes for required size	Y		9.5	10	11
			Y	0.95	1	1.1
104	Record Fin part number_serial Number			4.75	5	5.5
				0.95	1	1.1
105	Inspect vertical fin leading and trailing edges for cracks, corrosion and general condition	Y		9.5	10	11
			Y	0.95	1	1.1
106	Inspect vertical fin for cracks, corrosion and general condition	Y		19	20	22
			Y	1.9	2	2.2

Stage 4: Mechanical Component Inspection

DIS-ASSEMBLY TASK #	TASK NAME	Inspect	Record Findings	ESTIMATED TIME (MINS)	Lower (x0.95)	ESTIMATED TIME (MINS)	Upper (x1.1)
1	Inspect red main rotor blade assembly	Y		12	11.4	12	13.2
			Y	3	2.85	3	3.3
2	Inspect white main rotor blade assembly	Y		12	11.4	12	13.2
			Y	3	2.85	3	3.3
3	Inspect main rotor hub assembly	Y		12	11.4	12	13.2
			Y	3	2.85	3	3.3
4	Inspect flap Restraint assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
5	Inspect cone set	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
6	Inspect mast nut	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
7	Inspect mast nut lock	Y		0.5	0.475	0.5	0.55
			Y	0.5	0.475	0.5	0.55
8	Inspect pitch change links	Y		12	11.4	12	13.2
			Y	3	2.85	3	3.3
9	Inspect tail rotor hub and blade assembly	Y		17	16.15	17	18.7
			Y	3	2.85	3	3.3
10	Inspect bellcrank	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
11	Inspect rod assembly	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
12	Inspect spacer	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
13	Inspect static stop	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
14	Inspect Nut_A	Y		0.5	0.475	0.5	0.55
			Y	0.5	0.475	0.5	0.55
15	Inspect balance wheel	Y		0.5	0.475	0.5	0.55
			Y	0.5	0.475	0.5	0.55
16	Inspect knurled nut and liner	Y		9	8.55	9	9.9
			Y	1	0.95	1	1.1
17	Inspect tail rotor crosshead	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
18	Inspect Nut_B	Y		0.5	0.475	0.5	0.55
			Y	0.5	0.475	0.5	0.55
19	Inspect pitch link assemblies	Y		8	7.6	8	8.8
			Y	2	1.9	2	2.2
20	Inspect XMSN assembly	Y		26	24.7	26	28.6
			Y	4	3.8	4	4.4
21	Inspect swashplate assembly	Y		17	16.15	17	18.7
			Y	3	2.85	3	3.3
22	Inspect main rotor mast assembly			25	23.75	25	27.5
				5	4.75	5	5.5
23	Inspect XMSN isolation support assembly	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
24	Inspect LH and RH XMSN drag pins	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
25	Inspect LH and RH XMSN stop assemblies	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
26	Inspect LH and RH nuts	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
27	Inspect FWD LH nodal beam support mount	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
28	Inspect FWD RH nodal beam support mount	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
29	Inspect AFT LH nodal beam support mount	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
30	Inspect AFT RH nodal beam support mount	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
31	Inspect link assemblies_4	Y		26	24.7	26	28.6
			Y	4	3.8	4	4.4
32	Inspect arm assembly weights and retainer	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
33	Inspect arm assemlby RH FWD and LH AFT	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
34	Inspect arm assemlby LH FWD and RH AFT	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
35	Inspect LH and RH flexure assemblies	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
36	Inspect stop assemblies_4	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
37	Inspect stop assemblies_4_A	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
38	Inspect stop assemblies_4_B	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
39	Inspect washers_A	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55

40	Inspect washers_B	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
41	Inspect hydraulic reservoir assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
42	Inspect hydraulic pump rings and check valve	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
43	Inspect all hydraulic pump fittings for serviceability	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
44	Inspect hydraulic pump assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
45	Inspect tach generator	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
46	Inspect hydraulic solenoid assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
47	Inspect hydraulic filter_quick disconnect assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
48	Inspect all hydraulic flex and hard lines	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
49	Inspect hydraulic servos	Y		26	24.7	26	28.6
			Y	4	3.8	4	4.4
50	Inspect hydarulic manifold assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
51	Inspect hydraulic servo rack assembly	Y		26	24.7	26	28.6
			Y	4	3.8	4	4.4
52	Inspect hydraulic system brackets	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
53	Inspect XMSN oil system tubes	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
54	Inspect XMSN oil system flex hoses	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
55	Inspect XMSN oil system tube	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
56	Inspect XMSN oil system restrictor and bracket	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
57	Inspect swashplate boot and clamp	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
58	Inspect cyclic control tubes	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
59	Inspect collective control tubes	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
60	Inspect droop compensator link	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
61	Inspect droop compensator bracket and jackshaft assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
62	Inspect droop compensator bracket_B	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
63	Inspect droop compensator control assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
64	Inspect rotor brake master cylinder	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
65	Inspect rotor blade tubes (2 of each)	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
66	Inspect LH and RH engine mount trunnions	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
67	Inspect aft RH engine leg	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
68	Inspect aft LH engine leg	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
69	Inspect FWD LH and RH engine legs	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
70	Inspect mid LH engine leg	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
71	Inspect mid RH engine leg	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
72	Inspect engine exhaust duct	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
73	Inspect tach generators	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
74	Inspect starter generator adapter pad	Y		4.5	4.275	4.5	4.95
			Y	1.5	1.425	1.5	1.65
75	Inspect engine bleed air fitting	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
76	Inspect engine bleed aft hose and clamps	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
77	Inspect engine bellmouth assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
78	Inspect engine bellmouth pan assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1

79	Inspect engine bellmouth doubler	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
80	Inspect rotor brake calipers	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
81	Inspect rotor brake disk	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
82	Inspect rotor brake flex and rigid lines	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
83	Inspect droop compensator bracket & bellcrank assembly	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
84	Inspect droop compensator actuator	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
85	Inspect droop compensator lever assembly	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
86	Inspect gas producer nut_A	Y		0.5	0.475	0.5	0.55
			Y	0.5	0.475	0.5	0.55
87	Inspect gas producer ball joint	Y		0.5	0.475	0.5	0.55
			Y	0.5	0.475	0.5	0.55
88	Inspect gas producer nut_B	Y		0.5	0.475	0.5	0.55
			Y	0.5	0.475	0.5	0.55
89	Inspect gas producer tube assembly_A	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
90	Inspect gas producer nut_C	Y		0.5	0.475	0.5	0.55
			Y	0.5	0.475	0.5	0.55
91	Inspect gas producer rod end bearing	Y		0.5	0.475	0.5	0.55
			Y	0.5	0.475	0.5	0.55
92	Inspect gas producer bellcrank assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
93	Inspect gas producer RH and LH brackets	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
94	Inspect gas producer tube assembly_B	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
95	Inspect starter generator cooling duct assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
96	Inspect oil lines_8	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
97	Inspect fuel lines_2	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
98	Inspect oil and fuel drain lines_7	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
99	Inspect fuel filter assembly (including mounting bracket)	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
100	Inspect RH and LH scupper drains	Y		1.5	1.425	1.5	1.65
			Y	0.5	0.475	0.5	0.55
101	Inspect FWD short shaft assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
102	Inspect driveshaft adapters	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
103	Inspect engine pan covers_2	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
104	Inspect engine assembly	Y		26	24.7	26	28.6
			Y	4	3.8	4	4.4
105	Inspect main driveshaft assembly	Y		26	24.7	26	28.6
			Y	4	3.8	4	4.4
106	Inspect oil cooler	Y		26	24.7	26	28.6
			Y	4	3.8	4	4.4
107	Inspect oil cooler duct	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
108	Inspect oil cooler cover assembly	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
109	Inspect FWD and AFT oil cooler blower hanger bearing assemblies	Y		8.5	8.075	8.5	9.35

110	Inspect oil tank assembly	Y		13	12.35	13
			Y	2	1.9	2
111	Inspect oil hoses and lines	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
112	Inspect aft short shaft assembly	Y		13	12.35	13
			Y	2	1.9	2
113	Inspect driveshaft adapter	Y		4	3.8	4
			Y	1	0.95	1
114	Inspect facet Filter assembly	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
115	Inspect for compliance of decal and placard modifications	Y		26	24.7	26
			Y	4	3.8	4
116	Comply with 1200 hour inspection on anti-torque long tube assembly IAW MM Chapter 5	Y		40	38	40
			Y	5	4.75	5
117	Inspect hanger bearing to driveshaft assemblies	Y	¥	13	12.35	13
			Y	2	1.9	2
118	Inspect for compliance of upper LH tailboom fitting replacement IAW TB	Y		26	24.7	26
			Y	4	3.8	4
119	Inspect for tailboom assembly (repetition ??)	Y		108	102.6	108
			Y	12	11.4	12
120	Inspect for compliance of TB 206L-96-191	Y		17	16.15	17
			Y	3	2.85	3
121	Inspect elevators IAW PSE letter for applying sealant on installation	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
122	Inspect RH and LH elevator assemblies	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
123	Inspect horizontal assembly	Y		13	12.35	13
			Y	2	1.9	2
124	Inspect elevator control tube	Y		13	12.35	13
			Y	2	1.9	2
125	Inspect LH lower horizontal support panel	Y		4	3.8	4
			Y	1	0.95	1
126	Inspect RH lower horizontal support panel	Y		4	3.8	4
			Y	1	0.95	1
127	Inspect RH & LH finlets	Y		4	3.8	4
			Y	1	0.95	1
128	Inspect LH and RH slats	Y		4	3.8	4
			Y	1	0.95	1
129	Inspect tail rotor driveshaft cowling	Y		13	12.35	13
			Y	2	1.9	2
130	Inspect instrument line assemblies from pedestal to bottom of vertical tunnel	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
131	Inspect gas producer control assembly	Y		17	16.15	17
			Y	3	2.85	3
132	Inspect gas producer bracket assembly	Y		4	3.8	4
			Y	1	0.95	1
133	Inspect gas producer ball joint assembly	Y		4	3.8	4
			Y	1	0.95	1
134	Inspect gas producer adapter assembly	Y		4	3.8	4
			Y	1	0.95	1
135	Inspect gas producer rod end assembly	Y		4	3.8	4
			Y	1	0.95	1
136	Inspect anti-torque control tube assembly in horizontal box beam	Y		13	12.35	13
			Y	2	1.9	2
137	Inspect elevator control tube assembly in horizontal box beam	Y		13	12.35	13
			Y	2	1.9	2
138	Inspect box beam panels_6	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
139	Inspect elevator walking beam	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
140	Inspect anti-torque walking beam	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
141	Inspect elevatoréanti-torque walking beam mount assembly	Y		4	3.8	4
			Y	1	0.95	1
142	Inspect instrument line assemblies from bottom of vertical tunnel to top of vertical tunnel	Y		13	12.35	13
			Y	2	1.9	2
143	Inspect collective jackshaft assembly	Y		13	12.35	13
			Y	2	1.9	2
144	Inspect anti-torque dampener assembly	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
145	Inspect anti-torque FWD center bellcrank assembly between pedal assemblies	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
146	Inspect anti-torque control tube between center FWD bellcrank and dampener assembly	Y		4	3.8	4
			Y	1	0.95	1
147	Inspect anti-torque bellcrank assembly in bottom of vertical tunnel	Y		4	3.8	4
			Y	1	0.95	1
148	Inspect anti-torque control tube assembly between dampener assembly and bellcrank in bottom of vertical tunnel	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
149	Inspect cyclic torque tube assembly	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5

147	Inspect anti-torque bellcrank assembly in bottom of vertical tunnel	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
148	Inspect anti-torque control tube assembly between dampener assembly and bellcrank in bottom of vertical tunnel	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
149	Inspect cyclic torque tube assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
150	Inspect pilot's cyclic lever / pivot support base assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
151	Inspect copilot's cyclic lever / pivot support base assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
152	Inspect elevator bellcrank assembly in bottom of vertical tunnel	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
153	Inspect elevator control tube assembly from torque to bellcrank in bottom of vertical tunnel	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
154	Inspect feul vent cross T and vent lline in vertical tunnel	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
155	Inspect mixer assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
156	Inspect cyclic LH and RH yoke assemblies	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
157	Inspect cyclic stick balance spring bracket, eyebolt and spring assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
158	Inspect LH and RH cyclic control tubes from mixer assembly to servo rack assembly	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
159	Inspect collective control tube from mixer assembly to servo rack assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
160	Inspect anti-torque control tube assembly from bellcrank in bottom of vertical tunnel to bellcrank on bottom of servo rack	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
161	Inspect elevator control tube assembly from bellcrank in bottom of vertical tunnel to bellcrank on bottom of servo rack	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
162	Inspect FWD LH fuel cell pads and tape	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
163	Inspect FWD LH fuel cell	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
164	Inspect FWD LH fuel cell cover	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
165	Inspect FWD LH fuel quantity probe assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
166	Inspect FWD RH fuel cell pads and tape	Y		17	16.15	17	18.7
			Y	3	2.85	3	3.3
167	Inspect FWD RH fuel cell	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
168	Inspect FWD RH fuel cell cover	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
169	Inspect interconnect tube fitting in FWD AFT fuel cell	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
170	Inspect AFT fuel cell pads and tape	Y		26	24.7	26	28.6
			Y	4	3.8	4	4.4
171	Inspect AFT fuel cell	Y		40	38	40	44
			Y	5	4.75	5	5.5
172	Inspect fuel tube assemblies for fuel transfer system_Qty 3	Y		17	16.15	17	18.7
			Y	3	2.85	3	3.3
173	Inspect fuel transfer tube and interconnect tube in AFT fuel cell	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
174	Inspect fuel manifold assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
175	Inspect fuel wiring harness	Y		17	16.15	17	18.7
			Y	3	2.85	3	3.3
176	Inspect fuel transducer and fitting	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
177	Inspect fuel hoses in AFT fuel cell_Qty 5	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
178	Inspect fuel vent tube in AFT fuel cell	Y		4	3.8	4	4.4
				1	0.95	1	1.1
179	Inspect AFT fuel cell quantity probe assemblies_2	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
180	Inspect AFT fuel cell zipper	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
181	Inspect AFT fuel cell cover	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
182	Inspect interconnect tube assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
183	Inspect dual ejector pump assembly and tubing from pump to LH and RH fuel cells	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
184	Inspect fuel flow switches and tubing to dual ejector pump	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
185	Inspect inline Fuel filter_check valves and hoses	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
186	Inspect fuel transfer tube assembly	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
187	Inspect fuel boost pump assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65

184	Inspect fuel flow switches and tubing to dual ejector pump	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
185	Inspect inline Fuel filter_check valves and hoses	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
186	Inspect fuel transfer tube assembly	Y		4	3.8	4
			Y	1	0.95	1
187	Inspect fuel boost pump assembly	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
188	Inspect fuel shutoff valve assembly	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
189	Inspect fuel tubing from shutoff valve to engine pan	Y		13	12.35	13
			Y	2	1.9	2
190	Inspect fuel vent tubing from AFT fuel cell to vent drain	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
191	Inspect fuel flow switch fume cover panel	Y		4	3.8	4
			Y	1	0.95	1
192	Inspect fuel transfer tube cover panel	Y		4	3.8	4
			Y	1	0.95	1
193	Inspect FWD fuel probe panel	Y		4	3.8	4
			Y	1	0.95	1
194	Inspect AFT fuel probe panel	Y		4	3.8	4
			Y	1	0.95	1
195	Inspect collective stick assembly	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
196	Inspect cyclic stick assembly	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
197	Inspect pilots anti-torque pedal assembly	Y		4	3.8	4
			Y	1	0.95	1
198	Inspect copilots anti-torque pedal assembly	Y		4	3.8	4
			Y	1	0.95	1
199	Inspect pilots anti-torque pedal assembly_B	Y		4	3.8	4
			Y	1	0.95	1
200	Inspect copilots anti-torque pedal assembly_B	Y		4	3.8	4
			Y	1	0.95	1
201	Inspect anti-torque control tube from pilots pedal assembly to FWD center bellcrank	Y		4	3.8	4
			Y	1	0.95	1
202	Inspect anti-torque control tube from copilots pedal assembly to FWD center bellcrank	Y		4	3.8	4
			Y	1	0.95	1
203	Inspect LH AFT bulkhead panel	Y		4	3.8	4
			Y	1	0.95	1
204	Inspect RH AFT bulkhead panel	Y		4	3.8	4
			Y	1	0.95	1
205	Inspect RH and LH nodal beam support mount access panel	Y		2.5	2.375	2.5
			Y	0.5	0.475	0.5
206	Inspect fuel low level switch	Y		2.5	2.375	2.5
			Y	0.5	0.475	0.5
207	Inspect vertical tunnel closeout panel	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
208	Inspect fuel boost pump panel	Y		4	3.8	4
			Y	1	0.95	1
209	Inspect fuel shutoff valve panel	Y		4	3.8	4
			Y	1	0.95	1
210	Inspect aft facing center seat panel	Y		4	3.8	4
			Y	1	0.95	1
211	Inspect pilots seat pan	Y		4	3.8	4
			Y	1	0.95	1
212	Inspect copilots seat pan	Y		4	3.8	4
			Y	1	0.95	1
213	Inspect collective closeout			4	3.8	4
				1	0.95	1
214	Inspect upper LH pedestal panel	Y		4	3.8	4
			Y	1	0.95	1
215	Inspect lower LH pedestal panel	Y		4	3.8	4
			Y	1	0.95	1
216	Inspect upper RH pedestal panel	Y		4	3.8	4
			Y	1	0.95	1
217	Inspect lower RH pedestal panel	Y		4	3.8	4
			Y	1	0.95	1
218	Inspect radar altimeter panel	Y		4	3.8	4
			Y	1	0.95	1
219	Inspect pilot door	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
220	Inspect copilot door	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
221	Inspect litter door	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
222	Inspect RH aft passenger door	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
223	Inspect LH aft passenger door	Y		8.5	8.075	8.5
			Y	1.5	1.425	1.5
224	Inspect landing light panel	Y		4	3.8	4

221	Inspect litter door	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
222	Inspect RH aft passenger door	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
223	Inspect LH aft passenger door	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
224	Inspect landing light panel	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
225	Inspect XMSN oil tubing and drain valves_2 and drain tubes	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
226	Inspect oil cooler blower assembly drain tubing	Y		13	12.35	13	14.3
			Y	2	1.9	2	2.2
227	Inspect oil tank drain lines	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
228	Inspect top deck drain lines	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
229	Inspect fuel drain line from engine pan	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
230	Inspect engine pan drain tubing	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
231	Inspect anti-torque control tube assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
232	Inspect elevator control tube assembly	Y		8.5	8.075	8.5	9.35
			Y	1.5	1.425	1.5	1.65
233	Inspect cargo side panel	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
234	Inspect cargo aft wall panel	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
235	Inspect cargo ceiling Panel	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
236	Inspect tailboom access panel	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
237	Inspect cargo door	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
238	Inspect landing gear	Y		35	33.25	35	38.5
			Y	5	4.75	5	5.5

Stage 5: Avionics Electrical Component Inspection

TASK NAME	Remove / Instal	Inspect	Record Findings	**ESTIMATED TIME (MINS)**	**Lower (x0.95)**	**ESTIMATED TIME (MINS)**	**Upper (x1.1)**
Remove and inspect COM 1 system	Y	Y		26	24.7	26	28.6
Record COM 1_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect COM 2 system	Y	Y		26	24.7	26	28.6
Record COM 2_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect COM 3 system	Y	Y		26	24.7	26	28.6
Record COM 3_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect COM 4 system	Y	Y		26	24.7	26	28.6
Record COM 4_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect COM 5 system	Y	Y		26	24.7	26	28.6
Record COM 5_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect FWD audio panel system	Y	Y		12	11.4	12	13.2
Record FWD audio system_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect Rear audio panel system	Y	Y		13	12.35	13	14.3
Record Rear audio system_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect COM 3 Remote system	Y	Y		23	21.85	23	25.3
Record COM 3 Remote system_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect NAV system	Y	Y		23	21.85	23	25.3
Record NAV system_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect GPS system	Y	Y		23	21.85	23	25.3
Record GPS system_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect transponder system	Y	Y		13	12.35	13	14.3
Record transponder system_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect flight tracking system	Y	Y		23	21.85	23	25.3
Record flight tracking system_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect radar altimeter system	Y	Y		23	21.85	23	25.3
Record radar altimeter_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect AA34 interface system	Y	Y		13	12.35	13	14.3
Record AA34 system_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect attitude encoding system	Y	Y		6	5.7	6	6.6
Record attitude encoding system_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect ELT system	Y	Y		6	5.7	6	6.6
Record ELT_Part number_Serial number			Y	5	4.75	5	5.5
Remove and inspect ELT Avionics terminal blocks	Y	Y		16	15.2	16	17.6
			Y	1	0.95	1	1.1
Remove and inspect doctor_nurse headset assembly	Y	Y		4	3.8	4	4.4
			Y	1	0.95	1	1.1
Remove and inspect oxygen system equipment and wiring	Y	Y		9	8.55	9	9.9
			Y	1	0.95	1	1.1
Remove and inspect suction pump and inverter equipment and wiring	Y	Y		8	7.6	8	8.8
			Y	2	1.9	2	2.2
Remove and inspect night scanner system	Y	Y		10	9.5	10	11
			Y	5	4.75	5	5.5
Remove and inspect patient headset jack	Y	Y		9	8.55	9	9.9
			Y	1	0.95	1	1.1
Remove and inspect auxiliary light system	Y	Y		14	13.3	14	15.4
			Y	1	0.95	1	1.1
Remove and inspect avionics cooling fan assembly	Y	Y		9	8.55	9	9.9
			Y	1	0.95	1	1.1
				480		480	

Stage 6: Lifed Parts Overhaul

DIS-ASSEMBLY TASK #	TASK NAME	Record Life Data	TASK TIME (MINS)
1	Main Rotor Trunnion	Y	83.33
2	Latch Bolt	Y	83.33
3	Strap Retention Fitting	Y	83.33
4	Strap Retention Pin	Y	83.33
5	Main Rotor Grip	Y	83.33
6	Tension Torsion Strap	Y	83.33
7	Main Rotor Blades (2-off)	Y	83.33
8	Lower Cyclic Tube	Y	83.33
9	Collective Idler Link	Y	83.33
10	Swashplate Support Assembly	Y	83.33
11	Collective Lever	Y	83.33
12	Collective Sleeve Assembly	Y	83.33
13	Tail Rotor Gearbox Duplex Bearing	Y	83.33
14	Main Rotor Mast	Y	83.33
15	Freewheel Assembly Clutch*	Y	83.33
16	Tail Rotor Yoke	Y	83.33
17	Tail Rotor Blade (2-off)	Y	83.33
18	Powerplant - Turboshaft Engine	Y	83.33