INVESTIGATING REQUIREMENTS ENGINEERING AND MANAGEMENT PROCESSES IN SOUTH AFRICAN AEROSPACE AND DEFENCE INDUSTRY PROJECTS

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science in Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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ABSTRACT

Methods and process of Requirements Engineering and Management (RE&M) are indispensable in complex system development for cost saving, keeping up with timelines and deadlines, meeting target dates and increasing customer satisfaction. Fixing errors rises drastically the later in the complex system development process they are discovered. The highest savings can be achieved by focussing on finding errors, or avoiding them altogether, during the early stage of a project by effectively incorporating RE&M processes. Within South African aerospace and defence sector projects, missed milestones, increased costs, and project completion delays occur. The purpose of this research is therefore to investigate how-RE&M practices affect projects within the South African aerospace and defence sector. Case study method is used. This research report collects case study evidence primarily via interviews conducted with systems engineers, integration engineers, project managers and program managers within an organisation in the South African aerospace and defence sector. Cross-case analysis was used to facilitate the comparison of different cases. It allowed for the comparisons within the South African case studies as well as comparison between the South African and the US case studies. Results show that poor RE&M practices affect projects within the South African aerospace and defence sector. Poor RE&M practises affect areas of supplier selection, under estimating effort required for requirements traceability, as well as incorrect allocation of time for critical systems engineering activities. Project completion delays, missed milestones, dissatisfied customers and increased costs are attributed to poor RE&M. In addition there are other factors outside RE&M process that lead to project completion delays, missed milestones, dissatisfied customers and increased costs. The research adds to the body of knowledge on RE&M practices within the South African aerospace and defence sector and points to the need for continued research on the various

stages within system life cycle of complex systems development within South African aerospace and defence sector.

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LIST OF ACRONYMS

ACP	Audio Control Panel
AFIT	Airforce Institute of Technology
BAE	British Aerospace
CAS	Close Air Support
CCB	Configuration Control Board
COTS	Commercial Off The Shelf
DFS	Detailed Functional Specification
DOD	Department of Defence
FBL	Functional Baseline
GCS	Ground Control Stations
HOTAS	Hands-On Throttle And Stick
HREC	Human Research Ethics Committee
LRU	Line Replaceable Unit
MATS	Military Air Transport Service
MMI	Man Machine Interface
OC	Operational Capability
PDR	Preliminary Design Review
RBL	Requirements Baseline
RE&M	Requirements Engineering and Management
RFP	Request For Proposal
RM	Requirements Management

SAAF	South African Air Force
SANDF	South African National Defence Force
SL	Sea Level
TBC	To Be Confirmed
TBD	To Be Determined
TFR	Terrain Following Radar
UAOS	Unmanned Aerial Observation System
US DOD	United States Department of Defence
V&V	Verification and Validation
WBS	Work Breakdown Structure

1. INTRODUCTION

This chapter presents the background and motivation for the research as well as the research question, research methodology, research scope and limitations. The chapter closes with a description of the layout of the report.

1.1 Introduction

Requirements Engineering & Management (RE&M) is the overall term used to define all requirements related processes in product or system development. These processes include requirements elicitation and analysis, requirements specification, requirements validation and requirements management. In recent years more and more importance has been given to RE&M within organisations that develop complex products and services (Hood *et al* 2008). These organisations are realising that methods and process of RE&M are indispensable for cost saving, keeping up with timelines and deadlines, meeting target dates and increasing customer satisfaction (Hood *et al* 2008).

Boehm (1981) states that the cost of fixing errors rises drastically the later in the development process they are discovered (Figure 1) (Figure 2). Sheldon (1992) analysed a US Air Force project where 40%-60% of all errors were found in requirements, only a third of the errors were found in design and code (Figure 3). In other words: The highest savings can be achieved by focussing on finding errors, or avoiding them altogether, during the early stage of a project by effectively incorporating RE&M processes. Jones (2007) reports that the defect rate increases significantly in requirements that are injected late over those that are created prior to the start of implementation, and the most egregious defects in requirements defined or modified late in a project can sometimes show up in litigation.

Research conducted by the Standish Group and reported in the CHAOS Reports between 1994 and 1997 (Oberg *et al* 1999), established that the most significant contributors to project failure relate to requirements. The Standish Group's CHAOS report further established that managing requirements well was the factor most related to successful projects (Oberg *et al*. 1999). According to a survey conducted in 1996 (Oberg *et al* 1999); developers, managers and quality assurance personnel indicated that the majority of problems related to requirements were:

- Inability to track changes in requirements
- Difficulty in writing requirements
- Disorganised requirements
- A large number of sources for the requirements
- Many different types of requirements at different levels of detail
- A large number of requirements that often becomes unmanageable and uncontrollable

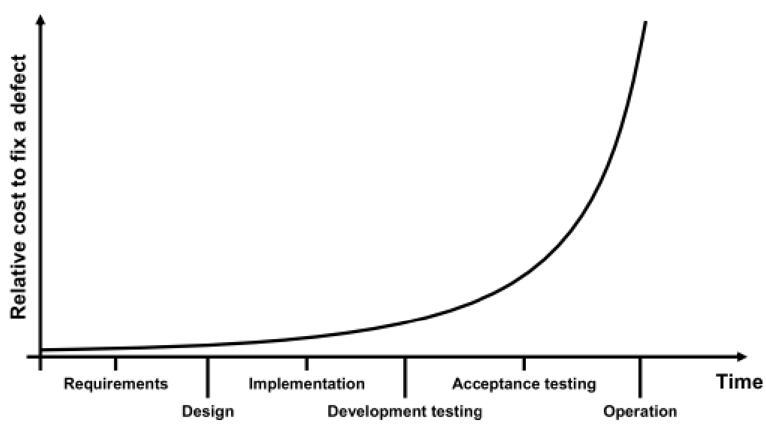

Figure 1: Relative cost of fixing a defect (Hood et al 2008)

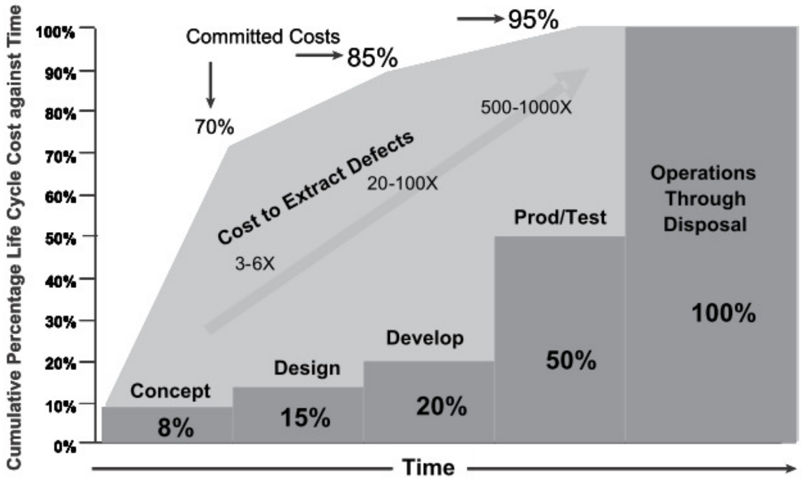

Figure 2: Committed Life Cycle Cost against time (Incose 2008)

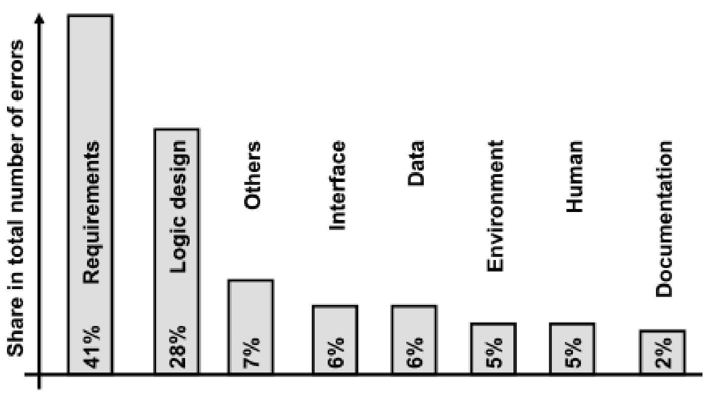

Figure 3: The share of errors in requirements in total number of errors (Hood et al 2008)

1.2 Purpose of this research

Within South African aerospace and defence sector projects, missed milestones, increased costs, and project completion delays occur. Prominent organisations within the South African aerospace and defence sector are running into ‘mammoth losses’ (DefenceWeb 2011). Systems engineers within the aerospace and defence sector point out that poorly written and incomplete specifications, misinterpretation of requirements by stakeholders, improper methods for capturing requirements, problems verification of requirements, poor management of requirements, poor traceability of requirements throughout the design and lack of requirements management tools are factors that greatly hamper aerospace and defence projects(ATE 2011).The purpose of this research is to investigate how RE&M practices affect projects within the South African aerospace and defence sector.

1.3 Work already done

Within the South African aerospace and defence sector, limited research has been carried out on RE&M processes. Malherbe and Malherbe (2009) state that updating or changing the requirements statement during the systems engineering process may impact adversely on project parameters and usually result in increased development time and costs. Furthermore, changes in the requirements statement that results in conflicting requirements may also have a negative impact on system solution.

1.4 Research question

There is very little publicly available research on RE&M processes and their effect on projects within the South African aerospace and defence sector. This needs to be investigated and leads to the following research questions:

1. How do RE&M practices affect projects within the South African aerospace and defence sector?
2. Are project completion delays, missed milestones, dissatisfied customers and increased costs attributed to poor Requirements engineering & management?
3. What needs to be done to improve RE&M processes within complex systems development in South African aerospace and defence sector?

1.5 Research methodology

This research uses case-study methodology. Projects within the United States Department of Defence (US DOD) are studied and used as guidelines and framework for projects within the South African aerospace and defence sector. Two projects within the South African aerospace and defence sector are studied. The case-study sources of evidence are documentation, archival records and interviews. Cross-case analysis is used to compare the projects in search of similarities, differences and patterns.

1.6 Research scope and limitations

This research is limited to RE&M processes within system development projects in the South African aerospace and defence industry.

1.7 Chapter outline

Chapter 2 reviews literature with regards to concepts in RE&M, these include criteria for good requirements, effective requirements practices and key success factors in RE&M

Chapter 3 outlines the research methodology used, the data sources, and the criteria used for sample selection. Ethical considerations are also discussed in this chapter.

Chapter 4 presents the case studies of projects within the United States department of defence as well as those within the South African defence industry. Learning principles of the case studies are presented based interviews conducted with engineers from the aerospace and defence sector.

Chapter 5 provides the results of the research as it is related to the research question and to the literature reviewed

Chapter 6 articulates the merits of this research and suggests recommendations

2. LITERATURE REVIEW

The purpose of this literature review is to explore key principles for consideration during RE&M processes, to establish the gaps in the literature, and to form a conceptual framework to use in the analysis of the US DOD case studies and the South African cases.

2.1 Introduction

Extensive RE&M research has been performed within systems engineering organisations and research institutes in the USA. Hood *et al* (2008) discuss the need for RE&M at various stages of complex system development. Berenbach (2008) discusses common misconceptions of RE&M. Olson (2007) discusses classification of requirements problems and describes some practical strategies that organizations can use to measurably improve their requirements process. Bahill and Dean (1997) discuss the steps to be followed for developing requirements in most systems. Biddle and Mortiz (2006) look at some factors that affect requirements instability. They further outline an approach for measuring requirements instability that takes contextual influences into account in order to provide insight as to why the requirements on a given program are unstable. Woodcock and Jones (2006) discuss self-defence strategies against the top 10 requirements crimes. This chapter explores key principles for consideration during RE&M processes. The focus of this literature review is to establish the need for RE&M; stating effective requirements practices; stating key success factors in RE&M; addressing requirements reuse, requirements traceability and requirements instability; and providing practical strategies that organisations can use to measurable improve their requirements process

2.2 System life cycle

Every system or product life cycle consists of the business aspect (business case), the budget aspect (funding), and the technical aspect (product). The systems engineer creates solutions that are consistent with the business case and the funding constraints (Incose 2008). The six life cycle stages (Table 1) of a system or product are (Incose 2008):

Concept: At this stage, stakeholders' needs are identified, concepts are explored and viable solutions are proposed

Development: At this stage system requirements are refined, solution descriptions are created, the system is built, and the system is verified and validated

Production: The system is produced, inspected and tested

Utilisation: The system is operated to satisfy the users' needs

Support: At this stage sustained system capability is provided

Retirement: The system is stored, archived, or disposed

This research focuses on the RE&M processes within the system life cycle.

Table 1:Life Cycle Stages and their purposes (Incose 2008)

LIFE CYCLE STAGES	PURPOSE
CONCEPT	*Identify stakeholders' needs* *Explore concepts* *Propose viable solutions*
DEVELOPMENT	*Refine system requirements* *Create solution description* *Build system* *Verify and validate system*
PRODUCTION	Produce systems Inspect and test [verify]
UTILIZATION	*Operate system to satisfy users' needs*
SUPPORT	*Provide sustained system capability*
RETIREMENT	*Store, archive, or dispose of the system*

2.3 The RE&M process

Stakeholder Requirements Definition Process

The purpose of the stakeholder requirements definition process (Figure 4) is to elicit, negotiate, document and maintain stakeholders' requirements for the system of interest within a defined environment. The inputs to this process include the description of users' needs or services that the system will provide, cost, schedule and solution constraints, terms and conditions of the agreement and industry specification and standards. The outputs of this process consist of formally documented and approved stakeholder requirements that will govern the project including: required system capabilities, functions and/or services; quality standards; cost and schedule constraints; concept of operations and concept of support (Incose 2008).

Requirements Analysis Process

The purpose of the requirements analysis process (Figure 5) is to review, assess, prioritize, and balance all stakeholders and derived requirements (including constraints); and to transform those requirements into a formal and technical view of a system description capable of meeting the stakeholders' needs. This view can be expressed in a specification, set of drawings or any other means that provides effective communication. The Inputs to the requirements analysis process is the baseline documented during the stakeholder requirements definition process. The output of requirements analysis is a technical description of characteristics the future system must have in order to meet stakeholder requirements which will be evolved in subsequent development processes (Incose 2008).

Requirements Management

Requirements management is the process of understanding and controlling changes to system requirements. It is important to keep track of individual requirements and maintain links between dependent requirements so that the impact of requirements changes can be assessed. A formal process of making change proposals needs to be established. The requirements management process should start as soon as a draft requirements document is available. However, planning on how to manage changing requirements should commence during the stakeholders' requirements definition process (Sommerville 2004).

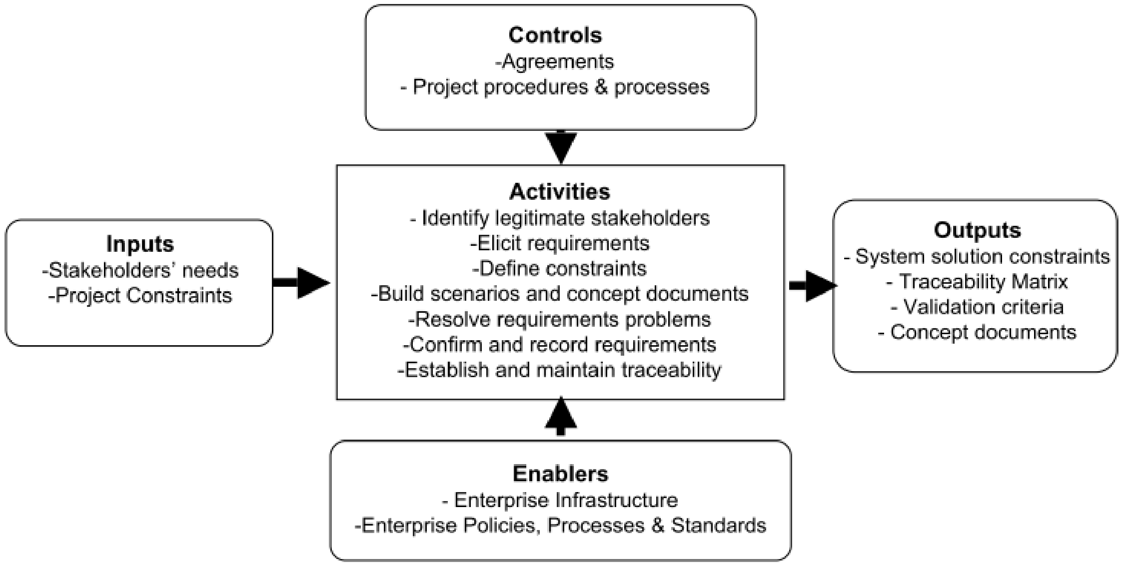

Figure 4: Context Diagram for Stakeholder Requirements Definition Process (Incose 2008)

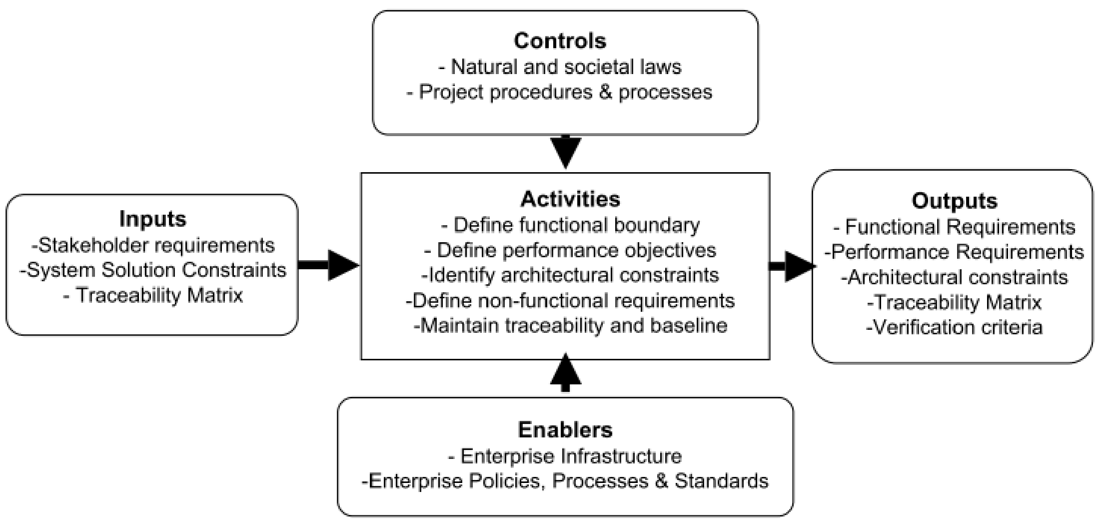

Figure 5: Context Diagram for the requirements analysis process (Incose 2008)

2.4 Need for RE&M at various stages of complex systems development

Within complex systems engineering projects RE&M methods are imperative at various stages (Hood *et al* 2008):

Project planning: The customer should allocate a budget of time and money before the bidding even starts, in order to produce a good requirements specification that will serve as a basis for the call for bids. Likewise, the contractors must have sufficient time to scrutinize the requirements specification and to write a target specification (Hood *et al* 2008).

Implementation: In a proper realization of RE&M best practices, a process is defined that controls the handling of changes at all stages of the project. As a result relevant stakeholders always have up-to-date project status (Hood *et al* 2008).

Acceptance: The final acceptance, by and large indicates the conclusion of a project. Acceptance can only happen if the acceptance criteria are met. The criteria should have been formulated in conjunction with the requirements (Hood *et al* 2008).

Version and configuration management: In organisations developing complex systems, there is a concept that directs the versioning and configuration of products. There is the definition of a product structure, a component structure and an organization structure. RE&M must develop an information infrastructure for specifying requirements based on these concepts, corresponding to the structures of organization, product and development (Hood *et al* 2008).

Design and architecture: The fundamental requirements must be plainly defined and consolidated sufficiently to build a stable architecture and design. Without this, a costly redesign of the architecture may be mandatory later on in the project (Hood *et al* 2008).

Finding solutions: RE&M support the capacity to innovate by making available elicitation methods for requirements on all levels and their traceability. User requirements are specified in ways that do not contain any unwarranted restrictions or solutions, due to technology or otherwise (Hood *et al* 2008).

Purchase and supplier management: RE&M can support the purchasing department with creation of the requirements specification, which is then sent to all prospective suppliers. In addition, it is expected that the suppliers create a target specification, where they give details on how they propose to solve the problem. The eventual decision is made by the purchasing and commissioning departments together (Hood *et al* 2008).

Test and verification management: Using the methods of RE&M, an up to date specification can be ensured at any time. This results in a precise agreement on the end product between the stakeholders. This forms a concrete basis for the creation of test cases (Hood *et al* 2008).

2.5 Classifying requirements problems

According to the software engineering institute (Christel *et al* 1992), problems of requirements elicitation can be grouped in three categories. These are problems of scope, in which the requirement may address too little or too much information; problem of understanding, within groups as well as between groups such as users and developers; and problems of volatility (Olson 2007)

2.6 Misconceptions about RE&M

Misconceptions about RE&M can greatly influence a company's processes. Many organizations have a solid comprehension of requirements processes, but some do not. Some common misconceptions are:

Any subject matter expert can become a requirements engineer after a week or two of training: Requirements analysts typically need significant training, both classroom and on the job, before they can create high-quality specifications (Berenbach 2008).

Non-functional and functional requirements can be elicited using separate teams and processes: The subject domains for non-functional and functional requirements are correlated, may influence each other, and may result in iterative changes as work progresses. Team isolation may do more harm than good (Berenbach 2008).

Processes that work for a small number of requirements will scale: Requirements engineering processes do not scale well unless crafted meticulously. Filtering and prioritization become important in order to retrieve results that can be better understood, but the requirement annotations necessary to provide such filtering are often neglected up front because the database is initially small (Berenbach 2008).

2.7 Criteria of a good requirement

Thirteen criteria for a good requirement are defined below. If all of these criteria have been satisfied, maybe then the requirement is as a well-formed requirement.

Necessary: If the requirement were removed or deleted, a deficiency would be created that cannot be fulfilled by other requirements. Nice-to-have requirements should be done away with (Sparrius 2009).

Implementation free: The requirement should state what must be done without indicating how. The treatment of interface requirements is generally an exception (Young 2001). The more abstract a requirement, the more competing alternatives are available.

Unambiguous: Can the requirement be interpreted in more than one way? If yes, the requirement should be clarified or removed (Young 2001).Every requirement shall be stated in such a manner that the likelihood of misinterpretation and misunderstanding by a non-expert is negligible. Danger signs include vagueness about the type of user and generalization words such as usually, generally, often, normally, typically (Sparrius 2009). Ambiguous or poorly worded writing can lead to serious misunderstanding and needless rework. Specifications should include a list of acronyms and a glossary of terms to improve clarity (Young 2001).

Achievable/Attainable: The requirement can be achieved in the system under development within the constraints of budget, schedule, the laws of physics and the current state-of-art of technology (Sparrius 2009).

Complete: All conditions under which the requirement applies are stated (Young, 2001). A requirement is complete if it contains all information necessary to implement it, including all constraints and conditions (Sparrius 2009).

Verifiable: Can one ensure that the requirement is met in the system? If not, the requirement should be removed or revised. The verification method and level at which the requirement can be verified should be determined explicitly as part of the development of each of the requirement. The verification level is the location in the system where the requirement is met e.g. system level, sub-system level (Young, 2001).

Concise: The requirement should be stated simply and clearly (Young 2001).The requirement includes only one single requirement (Sparrius 2009).

Correct: A requirement is correct if it contains no errors of fact (Sparrius 2009).

Consistent: The requirement should be met without conflicting with other requirements. If it does, the requirement should be revised or removed (Young 2001).

Allocated: Can the requirement be allocated to an element of the system design where it can be implemented? If not the requirement needs to be revised (Young 2001).

Standard Constructs: Requirements are stated as imperatives using “shall”. Statements indicating goals or using the words “will” “should” are not imperatives (Young 2001).

Traceable: Is the origin (source) of the requirement known, and can the requirement be referenced (located) throughout the system? The automated requirements tool should enable finding the location in the system where each requirement is met (Young 2001).

Unique identifier: Each requirement should have a unique identifying number that assists in identification, maintaining change history, and providing traceability (Young 2001).

2.8 Approaches to RE&M processes

Incose Systems Engineering Handbook (Incose 2008) suggests the following approaches and tips for RE&M processes:

- Established stakeholder requirements are to be placed under configuration management.
- Identify all stakeholders; it is critical to identify and include key system stakeholders in this process including the development and design team over the life cyle.
- Establish good relationships and open communication between requirements engineers and stakeholders. This is helpful when negotiations begin to refine and clarify the set of requirements
- Use of integrated product teams (customer and supplier participation) are an effective practise to bring together the necessary expertise
- Use of requirements management tools
- Begin from the very beginning to maintain requirements traceability
- Avoid deriving requirements that are not consistent with the other requirements or constraints
- Create templates for constructing requirements statements

2.9 Effective requirements practices

Young (2001) identifies the following crucial requirements practices that will reduce costs, improve quality of work products and increase customer satisfaction:

Commit to the approach: Commitment is vital to the success of any system development endeavour. Commitment requires the participants in the development effort dedicating themselves to the success of the project.

Establish and utilise a joint team responsible for the requirements: Experience has shown that a mechanism is required to be in control of the requirements all through the development effort. The joint team is a small group of people who are experienced and knowledgeable on the requirements and have the authority to make requirements decisions on behalf of the project. All stakeholders need to be represented.

Define the real customer needs: Customer's stated needs require thorough analysis to determine the real needs.

Use and continually improve a requirements process: A documented, reusable requirements process that integrates the mechanisms, methods, techniques, and tools that work in the environment and that is constantly bettered will save the project time and money.

Iterate the system requirements and architecture repeatedly: Iterating the system requirements and the system architecture repeatedly is an effective requirements practice. The systems engineering process provides three feedback loops (requirements, design, and verification) that facilitate creating a balanced system solution**.**

Use a mechanism to maintain project communication: Effective communications and coordination are fundamentals to project success. Proactive steps should be taken to promote effective communication. A project Configuration Control Board (CCB) can provide a mechanism for close and continuous communication and coordination of all the groups supporting a project.

Select familiar methods and maintain a set of work products: It is crucial to select methods and techniques that are familiar to the developers. Formal training in the use of the selected methods and techniques should be provided, particularly when they are new technologies**.**

Perform requirements verification and validation: The quality of the requirement can be improved, and costs and risks can be controlled by performing V&V planning early in the development process. Use of verification planning checklist facilitates asking the right questions.

2.10 Key success factors in RE&M

Barenbach (2008) states that the following key factors are necessary for successful RE&M in complex project development:

- The project should have a full-time, qualified chief architect
- An effective requirements management process must be in place
- Requirements elicitation should start with marketing and sales
- Requirements reviews should be conducted for all new or changed requirements or features;
- Requirements engineers should be trained and experience
- Requirements processes should be proven and scalable
- All stakeholders should be identified
- The customer should be is properly managed; progress and quality indicators should be well defined;
- The chosen requirements engineering tools should increase productivity and quality
- The core project team should be full time and report into a single chain of command.

- The majority of these factors can be assessed before project commencement.

2.11 Requirements reuse

When specifying the requirements for a system, a lot of effort and time can be saved if the requirements engineer starts by asking this question 'Have these requirements or any similar to them, already been specified?' Most systems that are designed and built are not entirely unique. Another system somewhere has already been built that contains some of the requirements germane to system being built. In many cases, a similar system within the organisation has already been built. Taking advantage of work that has already been done considerably increases efficiency. Successful reuse starts with having an organisational culture that consciously encourages reuse rather than reinvention. If an organisation has this outlook then the organisation is in a position to include requirements reuse in the requirements process (Robertson &Robertson 1999).

2.12 Requirements traceability

"Requirements traceability is the ability to describe and follow the life of a requirement, in both a forward and backward direction i.e. from its origins, through its development and specification, to its subsequent deployment and use, and through periods of on-going refinement and iteration in any of these phases" (Gotel and Finkelstein 994). Traceability can be a complex, overwhelming task, and is critical to the successful completion of a project. A requirement is traceable if the origin (source) of the requirement known, and the requirement can be referenced (located) throughout the system (Young, 2001). A recommended method of defining a traceability strategy is to look at the roles on the project and their needs, implementing tracing mechanisms only where required. Different projects will have different trace mechanisms for different reasons. A distinctive and costly blunder on projects is to wait until the analyses are needed before employing a traceability strategy (Berenbach 2008).

2.13 Requirements instability

Requirements instability, which results in modification, addition or deletion of existing requirements, tends to increase project risk (O'Neal and Carver 2001). Volatility factors adversely affect successful systems development (Russell 2004). A US DOD report on weapon systems acquisition cites lack of clearly defined and stable requirements as a key driver of cost increases, late deliveries and performance shortfalls (GAO2005). Initial program requirements that are specified in contracts and statements of works or capability description documents are often vague requirements documents are often vague or open to interpretation. Without some approach for managing requirements instability, the cost of requirements errors is signification and increases non-linearly across a program's life cycle. Some techniques for managing requirements instability include better up-front planning, better up-front design and innovative techniques such as eXtreme programming (Biddle and Mortiz 2006)

2.14 Requirements management tools

In order to keep track of the changes and to control and categorize the requirements, requirements management tools are necessary. A requirement management tool that augments a decision database should be accessible to and usable by all technical personnel on the project. Inputs to the database include draft specifications, comments, approvals, status data, change data, and requests. The tool should be able to generate the following directly from the database: Requirements documents with automatically generated project unique identifiers; requirements traceability matrices; requirements verification cross reference matrices; lists of TBDs and TBCs; specifications; and requirements metrics e.g. requirements stability. The tool should have configuration management capability to provide traceability of requirement changes, and to ensure that only changes that are properly authorized are made (Sparrius 2009).The followings should be considered when selecting a requirements management tool: Documentation of the history; traceability; analysis functions; tool integration; support for baselining of the requirements database; good support for tool-based communication among users

2.15 Strategies to improve the requirements process

Olson (2007) suggests the following strategies for improving requirements process:

- Use of formal configuration management to place requirements under formal baseline control;
- Use of a requirements management process
- Use of requirements metrics such as volatility, stability, priority, risk, size, quality, productivity, and cost metrics
- Define the requirements process
- Tailor a requirements standard
- Use early defect detection and defect prevention

2.16 The requirements discovery process

Bahill and Dean (1997) recommend the following steps be followed in developing requirements for complex systems:

- Identifying customers and stakeholders
- Understanding the customer's needs
- Defining and stating the problem

- Writing system requirements
- Reviewing requirements with the customer
- Defining performance and cost figures of merit
- Validating system requirements
- Defining technical performance measures and mitigating risks

2.17 Strategies against requirements crimes

Woodcock and Jones (2006), considers some faulty requirements practices and means of curbing them:

Too much chaff: These are requirements documents are large and broadly defined without any detailed information. A solution to this would be to isolate the relevant requirements from the full document set and return these to the customer for agreement.

Poorly organised requirements: Poorly organised requirements can lead to problems such as missing requirements, duplicate requirements, and contradictory requirements. A solution to this would be to offer the customer some assistance in the management of their requirements and a clear suggesting for an improved structure

Contradictory requirements: The solution for this would be to select the contradictory pairs of requirements and pass this back to the customer in a succinct format for resolution

Changing requirements: Project stakeholders are people, and people change their minds (Ambler 2006). A solution to this would be to agree a change management process with the customer and ensure that changes are controlled and considered in the agreed manner (Wiegers 2003)

Missing Requirements: A solution to this would be to firmly inform the customer that no work can begin until an agreed set of requirements is in place. The engineering team can offer to provide assistance (on a paid consultancy basis) (Woodcock and Jones 2006),

2.18 Managing changes in the requirements definition

Malherbe and Malherbe (2009) state that updating or changing the requirements statement during the systems engineering process may impact adversely on project parameters such as sequence, dependencies, effort and duration of tasks. This usually leads to an increase in development time and cost. Malherbe and Malherbe (2009) argue that all stakeholders, including the development team, should have an active participation in requirements formulation and refinement throughout the systems development process. Tacit and explicit knowledge of stakeholders should be included in the requirements statement to ensure requirements are complete and can successfully form the basis of an acceptable solution.

2.19 Summary

While several reports, articles and research studies are cited in the literature review regarding RE&M internationally, minimal research has been done to determine how RE&M practices affect projects within the South African aerospace and defence industry. This research report intends to address that gap.

3. METHODOLOGY

The purpose of this chapter is to discuss the chosen research methodology in relation to other research methodologies and to introduce and discuss research instruments that were developed and used. The chapter ends with a description of ethical considerations

3.1 Research methods

The research method is a strategy of enquiry, which moves from the underlying assumptions to research design, and data collection (Myers 2009). Although there are differences in research methods, the most common classification of research methods is qualitative and quantitative. Quantitative research refers to the systematic empirical investigation of phenomena via statistical, mathematical or computational techniques (Given 2008). The objective of quantitative research is to develop and employ mathematical models, theories and/or hypotheses pertaining to phenomena. Qualitative research is a method of inquiry employed in many different academic disciplines, traditionally in the social sciences, but also in market research and further contexts (Denzin and Lincoln 2005). Qualitative researchers aim to develop an in-depth understanding of human behaviour and the reasons that govern such behaviour. The qualitative method investigates the why and how of decision making, not just what, where, when. Neither of these research methods is intrinsically better than the other, the suitability of which needs to be decided by the context, purpose and nature of the research study in question. Within qualitative research there are various methods of data collection, these include focus groups, direct observations, in-depth interviews, diary methods, role-play and simulations, and case-study. This research paper uses qualitative research. The qualitative approach uses data obtained in the forms of words, gathered by the author, using the respondents' interpretation, knowledge and observations (Yin, 2003).

3.2 Case study research

Case studies have had a long history. In the social sciences, case studies became less prevalent a half century ago as the social science fields became more "scientific" and quantitative. Case studies were seen as having underlying problems of external and internal validity, and as well as construct validity and reliability (Yin 2003). With internal validity, the main questions are whether the findings were rationalised by the research and if problems of researcher bias were found. With external validity, the key question is whether the research findings could be generalised. With construct validity, the focal question is whether numerous sources for substantiation been used and have chains of evidence been adequately ascertained. With reliability, the leading question is, to what degree would other researchers who are studying the same case in precisely the same way arrive at comparable conclusions (Friedman and Sage 2003).

A new resurgence of interest in case study research has come about, particularly in evaluation research (structured interpretation and giving of meaning to predicted or actual impacts of proposals or results) in various areas such as enterprise management. This has led to the realisation that case study research can fill crucial needs. Modern case study research is able to contend with concerns of internal and external validity if the case study is well defined, developed, and deployed, with appropriate formulation, analysis and assessment, and interpretation. An archetypal attribute of case studies is that they corroborate a holistic understanding and interpretation of the systems of action, or interrelated activities engaged in by the participants or actors in the case situation subject to study (Friedman and Sage 2003).

Yin (2003) has summed up the key strengths and limitations implicit in case study designs. First, case studies are useful for addressing questions concerning how and why phenomena behave the way they behave. These case studies more frequently lead to hypotheses about behaviour rather than being useful for validating general claims about behaviour. Second, case study research often uncovers a rich detail of information that highlights the critical eventualities that exist among the variables in the case study. Finally, the case study method is particularly useful for exploration of topics when there is not a strong theory to which one can appeal. Even when there is a strong prescriptive theory, case studies can often lead to constructive insights, and potentially even to revision of the normative theories.

Case studies can comprise either single or multiple case designs. Single case designs are normally used to confirm or challenge a theory, or to represent a unique or extreme case of behaviour. Single case designs necessitate very careful investigation so as to steer clear of falsification and to allow maximum access by the researcher to pertinent evidence. Multiple case studies follow a replication logic in which each individual case study consists of a “whole” study in which appropriate information is amassed from a variety of sources and conclusions are drawn on the basis of information (Friedman and Sage 2003).

Yin (2003) has distinguished six sources of evidence in case studies. (1) Documentation, which could be letters, memoranda, agendas, administrative documents, newspaper articles, or any information believed relevant to the investigation. (2) Archival records can be organizational documents, official lists of names, survey data, and other such records. (3) Interviews represent a most important source of case study information. There are several forms of interviews: open ended, focused, and structured or survey. (4) Direct observations are obtained by such activities as field visits to a case study site, and other efforts to obtain data that range from the formal to the casual. It is thereby possible to cover events and contexts in real time. (5) Participant observations have many of the same strengths and weaknesses as direct observations. They may lead to insightful observation of interpersonal behaviour but are subject to bias if the case study researcher manipulates events in some ways. (6) Physical artefact observations may provide much insight into cultural features and technical operations. This research report collects case study evidence primarily via Interviews. Documentation and archival records are used secondarily.

There are at least five specific techniques for analysing case studies: pattern matching, explanation building, logic models, time-series analysis, and cross-case synthesis. These approaches are not mutually exclusive and use of multiple approaches will generally be very useful, whenever it is possible to do so (Friedman and Sage 2003). This research uses the cross-case analysis methodology in analysing case studies.

3.3 Cross-case analysis

Cross-case analysis facilitates the comparison of different cases. It allows for the comparison of multiple cases in many divergent ways, which would not be possible within a single case analysis. The case comparison can be made, in search of similarities and differences, or by classifying the data according to data sources (Abrahamsson 2003).

Eisenhardt (1989) argues that the cross-case analysis should preferably be used for searching patterns. The overall idea is to compel the researcher to go beyond the initial impressions using structured and diverse lenses on the data. Consequently, the prospect of attaining an accurate and reliable theory is enhanced. Three tactics are suggested: 1) select categories and look for within-group similarities coupled with inter-group differences, 2) select pairs of cases and list the similarities and differences between each pair and 3) divide the data by data source to exploit unique insights possible from different types of data collection (Abrahamsson 2003).

Cross-case searches for patterns and keeps investigators from attaining premature conclusions by requiring that investigators look at the data in various ways. Cross-case analysis divides the data by type across all cases investigated. One researcher then examines the data of that type exhaustively. When a pattern from one data type is affirmed by the evidence from another, the finding is stronger. When evidence differs, deeper probing of the differences is essential to identify the cause or source of conflict (Eisenhardt 1989). This is the process of triangulation of data. Triangulation is often used to indicate that more than two methods are used in a study with a view to double or triple checking results (Cheng 2005). The idea is that one can be more confident with a result if different methods lead to the same result. If an investigator uses only one method, the temptation is strong to believe in the findings. If an investigator uses two methods, the results may well clash. By using three methods to get at the answer to one question, the hope is that two of the three will produce similar answers, or if three clashing answers are produced, the investigator knows that the question needs to be reframed, methods reconsidered, or both (Wikipedia 2013).This research uses cross-case as the primary source of data is through interviews

3.4 Source of case study information

Interviews are used as the main sources of case study information. A questionnaire, Appendix A1, was used in face to face interviews with engineers and program managers. The resultant data is presented in chapter five, discussion of results, based on the responses shown in Appendix A2. A qualitative, cross-case analysis approach is used to analyse the open ended questions responses.

3.5 Population selection criteria

This research report considers two case studies of aircraft within the SANDF and uses three cases studies within the US DOD as a framework and reference. Given time frame restrictions as well as proprietary information constraints, samples were used to select respondents. Purposive sampling was selected as the suitable method. The purposive sampling technique also called judgement sampling is the deliberate choice of an informant due to the qualities the informant possesses. It is a non-random technique that does not need underlying theories or a set number of informants. Simply put, the researcher decides what needs to be known and sets out to find people who can and are willing to provide the information by virtue of experience (Tongco 2007).

In purposive sampling, sample sizes, which may or may not be fixed prior to data collection, depend on the resources and time available, as well as the study's objectives. Purposive sampling is successful when data review and analysis are done in conjunction with data collection (Tongco 2007).In this research; respondents were pre-identified before the interviews were conducted. Respondents were chosen based on their expertise and years of experience in the area of RE&M. Twelve persons were selected for interviews. The respondents occupied systems engineering, integration engineering, project management and program management positions.

3.6 Data collection techniques

There is no single best method of data collection. Face to face interviews is selected as the main interview technique. Other data collection methods used are, documentation and archival records. The verbal face to face interview is guided by a set of structured questions. The structured interview technique is selected as it promotes standardization of both the asking of questions and the recording of answers. The goal of this style of interviewing is to ensure those respondents' replies can be aggregated and this can only be achieved reliably if those replies are in response to identical clues (Bryman 2001). Interviews were conducted at the respondents' place of work. All interviews were audio recorded. Consent was provided by management and the respondents

3.7 Data analysis

Cross-case analysis is used to analyse the qualitative data. Cross-case analysis technique treats each individual case study as a separate study. Interviews are analysed using vertical and horizontal analysis. Vertical analysis involves reducing the volume of material by way of summary i.e. summarising and paraphrasing interview by interview. Horizontal analysis involves comparison i.e. relating texts to each other (Vavrus and Bartlett 2006).

3.8 Questionnaire design and format

It is important to create a set of questions to support the actual evidence collection process (Remenyi and Money 2006). The questions are set for the interviewer and not for the respondent and are a reminder or prompts to the interviewer concerning the information which is to be collected. The questionnaire can be found in appendix A1. The main RE&M areas covered in the questionnaire are:

- **RE&M roles with regards to contractors, subcontractors, suppliers and government bodies**: Questions 2 to 5 are linked to the areas of coordination and communication amongst the various organisations and stakeholders of the complex project.
- **RE&M problem areas as well as success areas:** Questions 7 to 9 are used to elicit, from experience engineers**,** core problem areas as well as successful practices of the RE&M
- **RE&M tools and support structures:** Questions 6 and 10 are used to draw out supporting tools and structures that aid in the RE&M process
- **Effect of RE&M on project completion, milestones, customer satisfaction, and costing:** Question 11 is a direct question to find out how RE&M affect project completion, milestones, customer satisfaction, and costing

A pilot was conducted with an integration engineer to test the appropriateness and adequacy of the questionnaire. The pilot revealed that some questions would be more appropriate for project and program managers as opposed to systems engineers and integration engineers. This was noted. Questions two, three and four of Appendix A1 would be emphasised when interviewing project and program managers. The title of the questionnaire was also elaborated to give more clarity to the respondent. The pilot study revealed that the average interview would take between twenty and thirty minutes. This time is neither too long as to introduce interview fatigue that could affect information quality nor too short as to gather insufficient information (Lavrakas 2008).

3.9 Research Limitations

The following constraints were identified during the research:

(1) The research survey is limited to the South African aerospace and defence sector.

(2) Due to proprietary information constraints, the research was limited to systems engineers, integration engineers, project managers and program managers within one organisation. Despite this fact, the engineers and managers interviewed had a minimum of seven years' experience within various aerospace and defence industries within and outside of South Africa. In addition interviews were conducted with respect to two different aerospace and defence projects.

(3) Due to constraints with regards to time and availability of the respondents, seven participants were interviewed.

(4) The individuals who were interviewed are known to the interviewer from having being colleagues and managers of the interviewer. This could be perceived as shaping the responses given to the questionnaire. These relationships allowed the interviewer to access to persons that would otherwise been unavailable.

3.10 Ethical Considerations

This research is not socially or psychologically invasive or damaging. This research respects the rights of individuals and ensures that the informant or subject has consented to the research without coercion; the questions posed are not insulting or embarrassing; confidential matters that could place the informant in an embarrassing, false or compromising position vis-à-vis authorities, are handled circumspectly; The privacy and wishes of informants are respected, i.e. anonymity of the informant is maintained if required; The informant is informed as fully as possible as to the aims and possible implications of the research. If need be, clearance will be obtained from the Human Research Ethics Committee (HREC Non-Medical).

4. CASE STUDIES

This chapter presents the case studies of projects within the United States department of defence as well as those within the South African defence industry.

4.1 Concept of Learning Principles

The concept of learning principles was developed by the USA DOD. The USA DOD leadership collectively stated the need to mature a sound systems engineering (which includes RE&M) process throughout the defence force. Gaining an understanding of the past and distilling lessons learned that are then shared with others is critical to achieving continuous improvement. Results of case studies are conveyed as learning principles to facilitate pedagogy. The results are also useful to practicing engineers and managers as they apply systems engineering throughout complex systems development life cycle AFIT (2010). This research uses learning principles to convey results of the case studies.

4.2 United States Department of Defence Case Studies Data and Analysis

4.2.1 C-5A Galaxy

System Description

The C-5A cargo aircraft was conceived in the early 1950s by senior leadership in the US Air Force and the Military Air Transport Service (MATS). It was becoming increasingly clear that the nation would be engaged in conflicts arising in distant locations, and senior military planners contemplated methods to employ forces that could quickly stop an advancing enemy. They envisioned a very large transport aircraft capable of carrying the heaviest of the Army M-60 tanks, large bulky cargo such as the Chinook CH-47 helicopter, and other heavy Army equipment for extremely long distances. The aircraft was to be part of a family of jet engine-powered platforms that would transport an entire Army division to the war front (Griffin 2005).

C-5A Characteristics

Design weight: 764,000 pounds[1]
840,000 pounds[2]
920,000 pounds[3]
Max payload: 265,000 pounds[4]
Max fuel: 335,000 pounds
Max landing weight: 635,850 pounds
Cruise performance: 440 knots at 30,000 feet
Airport performance (Take off): 440 knots at 30,000 feet
Airport performance (Landing): 4,000 feet with 100,000 pound cargo

C-5 Requirements Engineering and Management Learning Principles

The learning principles related to requirements engineering and management are as follows

Learning Principle-1: Developing and documenting system requirements

The process for developing and documenting the system performance requirements integrated the user (warfighter), planners, developers, and technologists from both the government and industry in a coordinated set of trade studies. It resulted in a well-balanced, well-understood set of

[1]At 2.25g
[2]With the new wing
[3]In flight limit after refueling
[4]With new wing

requirements that fundamentally remained unchanged throughout the program Griffin (2005).

Learning Principle-2: Weight empty guarantee performance requirement

A Weight Empty Guarantee (allocation of aircraft empty weight throughout the subsystems and structure of the aircraft) was included in the specification as a performance requirement and in the contract as a cost penalty for overweight conditions of delivered aircraft. The aircraft weight empty guarantee dominated the traditional aircraft performance requirements (range, payload, etc.), increased costs, and resulted in a major shortfall in the wing and pylon fatigue life. The stipulation of a weight empty guarantee as a performance requirement had far-reaching and significantly deleterious unintended consequences Griffin (2005).

4.2.2 F-111

F-111 System Description

The F-111 aircraft, the first US production fixed-wing flight vehicle, is a supersonic all-weather multipurpose tactical fighter bomber developed on account of the US DOD plan for a single aircraft to meet both a Navy fleet-defence inceptor requirement and an Air Force supersonic strike aircraft requirement. The F-111 has variable-sweep wings that allow the pilot to fly from slow approach speeds to supersonic velocity at sea level and more than twice the speed of sound at higher altitudes. Wings sweep from 16 degrees to 72.5 degrees. With wings fully extended, the F-111 can take off and land in as little as 2,000 feet, although the brakes get very hot on short landings. With wings fully swept back, it can reach supersonic speeds at high or low altitudes. The F-111 can operate from tree-top level to altitudes above 50,000 feet. Full-forward wings give the most surface area and maximum lift for short take-off and landing. The F-111 needs no drag chute or reverse thrust to slow down after landing (Richey 2005).

The F-111 provided many firsts among weapons systems. It was the first production aircraft with variable sweep wings that could be swept back or brought forward to increase efficiency. It also had the first terrain-following radar, enabling it to fly at night at high speeds and low altitudes, as well as the first crew escape module. The two crew members sit side-by-side in an air-conditioned, pressurized cockpit module that serves as an emergency escape vehicle and as a survival shelter on land or water (Richey 2005).

The avionics systems include communications, navigation, terrain following, target acquisition and attack, and suppression of enemy air defence systems. A radar bombing system is used for precise delivery of weapons on targets during night or bad weather. The PAVE TACK forward-looking infra-red seeker was introduced into F-111Fs in 1984, and significantly enhanced the ability of the F-111 to acquire, recognize, and laser-designate a target with precision. The F-111's automatic terrain-following radar (TFR) system flies the craft at a constant distance above ground level, following the Earth's contours. It allows the aircraft to fly in valleys and over mountains, day or night, regardless of weather conditions. Should any of the system's circuits fail, the aircraft automatically initiates a climb. The system meets the original proposal specification and works reliably (Richey 2005).

F-111 Characteristics

Primary Function: Multipurpose tactical fighter bomber.

Contractor: General Dynamics Corporation.

Length: 73 feet, 6 inches.

Height: 17 feet, 1 1/2 inches.

Wingspan: 63 feet full forward; 31 feet, 11 1/2 inches full aft.

Speed: F-111F -- Mach 1.2 at sea level; Mach 2.5 at 60,000 feet.

Ceiling: 50,000-plus feet.

Range: 3,565 miles (3,100 nautical miles) with external fuel tanks.

Weight: F-111F, empty 47,481 pounds.

Maximum Take-off Weight: F-111F, 102,000 pounds

Armament: Up to six nuclear bombs on four pivoting wing pylons, and two in internal weapons bay. Wing pylons carry total external load of 25,000 pounds of bombs, rockets, missiles, or fuel tanks.

Unit cost: $18 million.

Crew: Two; pilot and weapon systems officer.

Date Deployed to USAF: October 1967.

Date retired from USAF: 1996.

F-111 Requirements Engineering and Management Learning Principles

The learning principles related to requirements engineering and management are as follows

Learning Principle-1: Ill-conceived, difficult-to-achieve requirements and attendant specifications made the F-111 system development extremely costly, risky and difficult to manage

In a sound systems engineering approach to a major weapon system development, the system requirements and specifications are exhaustively assessed from effectiveness, cost, and technical risk aspects before commencing with the program, and they are held constant as much as possible all through the development program. In the case of the F-111, the development of a set of specifications founded on service requirements was gravely unsound. The underlying issue was the dissimilar requirements for speed, altitude, range, and weight between the air force's requirement for a low-altitude penetrator (at Mach 1.2 Sea Level) and high altitude supersonic (Mach 2.5) fighter/interceptor, and the navy requirement for a subsonic fleet defence missile launcher which could operate at long distances from the fleet for extended periods of time to detect and destroy enemy aircraft outside the range at which they could launch anti-ship missiles (Richey 2005).

Learning Principle-2: Requirements shall flow down in a logical and traceable manner from the top level to all lower levels of the system being engineered.

Contractor attempted to meet incongruent air force and navy requirements in the design. The proposed (paper) design met the requirements but as the system evolved, the capability for sea level (SL) dash distance, ferry range, max mach and carrier suitability in terms of weight and wind-over-deck diminished (Richey 2005).

Learning Principle-3: Customer and contractor shall share the state of technical maturity for new, first-time procurements.

The state of technical maturity was not well interpreted by either contractor or government in the case of inlet-engine compatibility (dynamic distortion) and structural fracture mechanics of brittle materials. Technical maturity of terrain-following radar was generally understood (Richey 2005).

Learning Principle-4: The government shall incorporate the needs of its user organizations with the management activities of its developmental organizations.

It appears that the air force and navy set their requirements independently and did not work out a set of mutually acceptable joint requirements (Richey 2005).

Learning Principle-5: The systems architecture should be established early for the reasons stated above and the best judgment of both government and contractor shall be employed across all the key issues, including the choice of employing newly developed or legacy systems.

The government provided the systems architecture specifications and the contractor responded, although there were concerns expressed by navy and air force analysts that the disparate range of system architecture requirements could be met while maintaining the required level of commonality (Richey 2005).

Learning Principle-6: System design shall proceed in a logical and orderly manner through a process of functional decomposition and design traceability that originates with the system functional architecture and ultimately results in design specifications for the system to be engineered.

General Dynamics used a sound WBS which was supported by General Dynamics engineering to achieve the design specs. They maintained vigilance on impact of technology or design shortfalls, such as weight growth, on the system architecture requirements (Richey 2005).

Learning Principle-7: The customer shall share high level measures of effectiveness with the contractor, thereby ensuring that the proposals selected for funding are those which are most responsive to all stakeholders, especially the operational organizations.

The system measures of effectiveness were defined by the government in general terms but there is little evidence that quantitative effectiveness analysis was done in depth to support trade-off studies. The AF and Navy development engineers believed they were representing the end-item users but in 1960's there was less coordination between developers and users than there was in later systems' developments.

Learning Principle-8: The government shall assure that all its operational systems – in development, in operation, or in planning – are compatible and mutually supportive in a broad "system of systems" and "federation of systems" context.

The original RFP addressed the overall "system of systems" in an operational framework. The specifications did not change drastically during the development program although many of the original requirements were never met. In hind-sight, there should have been more operation/systems trade off studies on the key performance parameters to establish cost/benefit/risk factors (Richey 2005).

Learning Principle-9: Every requirement shall have a test and every test shall have a requirement which requires validation and verification. The

criteria for determining test success and failure shall be established early in the program, as shall verification and validation measures. General Dynamics had a sound test and validation plan in key areas such as aircraft performance, avionics performance and other test areas. The test plan was consistent with the WBS. The test plan did not explore test points outside the specified limits, such as structural failure modes or inlet-engine compatibility, but these were unknown to the contractor and government early in the development cycle; General Dynamics did address these and other issues as needed in the development of the F-111, albeit with negative impact on cost and schedule (Richey 2005).

4.2.3 A-10 Thunderbolt II (Warthog)

A-10 System Description

The A-10A Thunderbolt II, manufactured by Fairchild Republic Corp. between 1975 and 1984, was exclusively designed as a Close Air Support (CAS) aircraft. It was named after another aircraft manufactured by Republic Aircraft, the P-47 Thunderbolt of WW II fame, but is generally referred to by its nickname, “Warthog”, due to its odd look. The A-10, which has endured numerous efforts of program termination and premature retirement, is now expected to operate until 2028, well past its initial requirement. The A-10 has numerous configurations including the original A-10A, the A-10B, a two-seat variant intended for all-weather/night attack and pilot training (only one was produced), the OA-10A, used for forward air controller (FAC) missions, and the recent A-10C, an upgraded version of the A-10A (Jaques and Strouble 2007).

The main roles of the A/OA-10 comprise close air support, forward air controller, combat search and rescue, special operations, and interdiction. The A-10 was developed at the same time as the GAU-8/A 30 mm gun system which it carries internally. A-10s have excellent manoeuvrability at low air speeds and altitude, and are highly accurate weapons-delivery platforms. They can loiter near battle areas for extensive periods of time and operate under 1,000-foot ceilings (303.3 meters) with 1.5-mile (2.4 kilometres) visibility. Their wide combat radius and short take-off and landing capability allows for operations in and out of locations near front lines. The pilots are protected by titanium armour that also protects parts of the flight-control system. The redundant primary structural sections allow the aircraft to benefit from better survivability from ground fire than most aircraft. The A-10’s have self-sealing fuel tanks, and dual redundant hydraulic flight controls with manual back-up. The A-10 can be serviced and operated from bases with minimal facilities in the vicinity of battle areas. Many of the aircraft's parts are interchangeable left and right, including the engines, main landing gear and vertical stabilizers (Jaques and Strouble 2007).

Close consideration to primary mission characteristics (lethality, survivability, responsiveness, and simplicity) permitted the concept formulation and consequent system design to result in an effective CAS aircraft, and design-to-cost goals kept the government and contractor focused on meeting the critical requirements at an affordable cost. The A-10 did not comply with all its cost goals, but it came much closer to them than most major defence development programs did in that time frame or since then (Jaques and Strouble 2007).

There were numerous characteristics of the A-10 program that were unique for its day. It was a design-to-cost program when most other aircraft programs were plainly putting performance first. It was the foremost defence program to adopt the newly favourable competitive prototyping approach to allow a source selection choice to be made on the basis of demonstrated performance and maturity of the design. It may be the sole aircraft program ever designed around the armament (the GAU-8/A gun system), and it was distinctive in how it carried out the development of the gun and its associated ammunition as part of the overall A-10 program. Both the A-10 and its gun were required to prove themselves in multiple comparative “fly-offs”, and even more “fly-offs” were threatened but never occurred (Jaques and Strouble 2007).

Unfortunately, no program is without fault, and the A-10 provides no exemption to that observation. Unobserved problems linked to production readiness and contractor financial stability did not recede and had to be resolved far too late in the development program. More notably, the initial structural design proved sub-standard for the design life, and even fixes during production were insufficient for all but the latest aircraft produced. This problem was intensified by loss of the original equipment manufacturer (OEM), on-again/off-again decisions to retire the A-10, unpredictable funding for inspection and repair, and major personnel disruptions resulting from a Base Realignment and Closure (BRAC) decision. Critical "health of the fleet" structural inspections were not carried out during sustainment, and a successive repair program failed to provide the required level of life extension. In spite of these problems, the A-10, with precision engagement upgrades and new wings in production, seems to be back on course for a life extension that will double its service life and keep it in operation until 2028(Jaques and Strouble 2007).

A-10 Characteristics

Primary Function: A-10 – Close air support
OA-10 – Airborne forward air control

Crew: One Pilot

Contractor: Fairchild Republic Co.

Date Deployed: March 1976

Length: 53ft, 4in

Height: 14ft, 8in

Wingspan: 57ft, 6in

Power Plant: Two General Electric TF34-GE-100 turbofans

Thrust: 9065 lbs each engine

Speed: 420mph (Mach 0.56)

Ceiling: 45,000 ft

Range: 800mi

Maximum Take-off Weight: 51,000 lbs

Armament: One GAU-8/A seven-barrel Gatling gun

: Up to 16,000 lbs of mixed ordnance, AGM-65 Maverick missiles, and laser-guided bombs

: Infrared and electronic countermeasures

: 2.75 in rockets

: Illumination flares

: AIM-9 Sidewinder missiles

A-10 Requirements Engineering and Management Learning Principles

The learning principles related to requirements engineering and management are as follows

Learning Principle-1: The system concept and preliminary design must follow, not precede, the mission analysis

The A-10 would have been a very different aircraft had this principle been violated. The obvious preference within the air force at the time of needs definition was for fast multi-purpose aircraft. By concentrating on the close air support mission, and focusing on key characteristics of that mission, the early A-X concept working group was able to discover what the critical performance parameters were that contributed to these characteristics. An example of this approach is how the group treated the primary mission characteristic of responsiveness. While a contributor towards responsiveness can evidently be aircraft speed, the group understood that responsiveness was even more reliant on how close to the battlefield the aircraft could be based and maintained, how long the aircraft could loiter around the battlefield, and whether or not the pilot could effortlessly communicate and coordinate with the ground troops they were supporting. The aircraft performance parameters were evaluated in terms of alternative design methods and aircraft design parameters in areas of airframe and propulsion, avionics, armament, and survivability provisions. Once those design parameters were comprehended and traceable back to mission characteristics, the study group was able to assess contending aircraft configurations in terms of mission and cost effectiveness. This front end application of systems engineering resulted in comprehensive requirements and provided a solid foundation with which to request contractor proposals and commence a development program(Jaques and Strouble 2007).

A component of the A-X concept from the start was a low ownership cost. While the A-10 did not meet its intended design-to-cost goal, the cost driven approach filtered through all aspects of the design, development and production of the aircraft. The design was largely compelled to use "existing state-of-the-art" technology, avionics were kept to a minimal set necessary to carry out the primary missions, and the design integrated many features to decrease the maintenance and support cost for the aircraft. An example of this is the attention paid to reducing the cost associated with the ammunition, the majority driver for ownership cost of the gun system. The program paid more in the development effort (due to multiple ammunition subcontractors) to ensure a low production cost would be achievable when it came time for large competitive contracts for ammunition to support operational use (Jaques and Strouble 2007).

4.3 South African National Defence Force Case Studies

4.3.1 Lead In Fighter Trainer (LIFT) Hawk

The South African Air Force (SAAF) Hawk Mark 120 Lead In Fighter Trainer (LIFT) aircraft is a derivative of the BAE SYSTEMS Mark 100 Hawk series, designed and built by BAE SYSTEMS of the United Kingdom since the mid-1990s. The aircraft has a newly developed local Avionics Suite by Advanced Technologies Engineering (ATE). Local Industry has been involved in various elements of the engineering, training and support deliverables (SAAF2012).

System Description

The Hawk is a transonic lead-in fighter trainer (LIFT) encompassing ideal handling characteristics for fighter training and is capable of demonstrating supersonic flight in a dive. The aircraft can train aspirant fighter pilots in all aspects of modern fighter flying. In the case of the Hawk Mk 120, the cockpit has been specifically tailored to seamlessly and cost effectively train pilots graduating from the SAAF Astra basic trainer to the SAAF Gripen front line fighter. The Adour 951 engine introduces full authority digital engine control (FADEC), care free handling and a maximum thrust output of 6500 lbs. The power to weight ratio and good sustained turn rates provide an ideal flight envelope and performance domain to step from the Astra to the Gripen. The Hawk has an open architecture avionics system which allows for efficient training in a systems environment and gives the aircrew a high situational awareness. Aircrew awareness is further enhanced by a simulated radar, multi-functional displays and hands-on throttle and stick (HOTAS). External fuel tanks and an air refuelling capability enhance the range of the aircraft. The combination of the above factors ensures a very capable lead-in fighter-trainer aircraft (SAAF 2012).

The primary role of the Hawk Mk 120 is all aspects of air combat training for the SAAF's air and ground crews from aircraft type conversion to full mission training during a deployment. This includes joint training with the other arms of service and participation in operational training exercises. The 24 Hawks replaced the 250 Impala Mk 1 and Mk 2 aircraft phased out in late 2005. They are based at AFB Makhado. By nature of the Hawk's inherent training capabilities, certain collateral operational tasks in a low threat environment are envisaged for the aircraft. These will be developed and implemented over the next few years and may include the following (SAAF 2012).:

a. Search and Rescue
b. Communications
c. Border Patrol
d. Reconnaissance
e. Limited Close Air Support.

LIFT HAWK Characteristics

Crew: 1-2

Length: 12.43 m (40.78 ft)

Wingspan: 9.075 m (29.77 ft)

Height: 3.98 m (13.06 ft)

Empty weight: 4,530 kg (9,987 lb)

Loaded weight: 8,720 kg (19,200 lb)

Max takeoff weight: 9,100 kg (20,062 lb)

Powerplant: 1× Adour Mk 951 with 6500 lb thrust

Wheel track: 3.47 m (11.38 ft)

Maximum speed: 500+ kts (1 000 km/h)

Range: Around 900 Nm clean. Can carry drop tanks and do A-A refueling for extended ranges

Service ceiling: 40,000 ft plus

Armament: 5 x underwing and 2 x wingtip stations

: 1 x 30mm Aden gun pod

: Provision for up to 2 x wingtip short-range infrared A-A missiles

: 5 x CBLS2000 with 4 x 12.5 kg smoke and flash practice bombs

: Series of local Mk 81 bombs

: Simulated weapons (all of the above)

4.3.2 Vulture

System Description

Vulture is an Unmanned Aerial Observation System (UAOS) in operation within the South African National Defence Force (SANDF). It is used for target acquisition, fall-of-shot detection and fire correction support of towed and self-propelled gun howitzer systems of artillery formations. It operates without a pilot or a runway and is deployable in 30 minutes in unprepared terrain. The vulture system is assembled by ground personnel on the launcher and is launched automatically by the atmospheric catapult launcher. Once deployed the Vulture is monitored on the ground via the navigator and observer screens in the Ground Control Stations (GCS). A laser system is used for automated approach, an arrestor system for its capture and an inflatable airbag for its recovery. With a digital and secure data link qualified at 200km range, Vulture is ideally suited for the role of tactical reconnaissance missions (Unmanned 2011).

Vulture Characteristics

Range Class: Tactical
Airframe: High wing monoplane with single pusher propeller
Span: 5.20 m
Length: 3.10 m
Max take-off weight: 100.00 kg
Payload Weight: 25.00 kg
Cruise speed: 65.00 kts
Endurance: 3-4hr

The Vulture was developed to support South African army artillery spotting requirements under initial contracts placed in 1993. The Vulture is tailor-made to suit the harsh african environment. It is deployable in 30 minutes in an unprepared terrain. Furthermore, the take-off and landing (recovery) of the aircraft is fully automated. In other words, the system does not require a runway. This feature makes the system unique and highly sophisticated (Unmanned 2011).

5. RESULTS AND DISCUSSION OF RESULTS

This chapter analyses the LIFT and Vulture case studies individually (vertical analysis). Subsequently a comparison of LIFT and Vulture case studies is discussed. The similarities and differences are noted (horizontal analysis). The results of the SANDF case studies are then compared to the US DOD case studies. The case studies are analysed as per responses to the questionnaire.

5.1 Reliability and validity

Validity of this research is increased by use of different data collection instruments. Interviews, documentation and archival record are used as data collection methods. Horizontal and vertical analysis within the cross-case analysis technique are used to summarise as well as compare data. This method of analysis increases reliability. Triangulation of data by analysing similarities and differences within the data collected is performed. Triangulation provides different views of the case and thereby avoids the problem of observer bias (Cheng 2005).

5.2 Analysis of Lift Hawk Case Study

1. Your function/role in this project

The response to this question addresses the fact that respondents are all experienced engineers. Respondents performed various engineering functions within the aerospace and defence engineering projects. These include integration engineering, component management, systems engineering, data analysis, safety management, program management and technical management. Respondents were chosen based on their expertise and years of experience

2. **For this project, discuss main contractor's role, government's role or sub contractor's role w.r.t Requirements engineering & management**

Within the LIFT Hawk program, the main contractor was BAE systems, the main client was the air force (SAAF) and Armscor was the government body acting on behalf of and together with the client. Organisation A was a subcontractor. The following points were observed:

i. Respondents responses differ w.r.t to the roles of the main contractor, government and subcontractors.
ii. At some point the client (SAAF) felt that the requirements were not correctly implemented.
iii. The requirements process involved the main contractor (BAE systems) and the client (SAAF). The subcontractors had little involvement in the initial requirements process i.e. there was little visibility of the initial requirements process to the subcontractors. Furthermore systems engineers at subcontractor level had no information on higher level requirements.
iv. There is a suggestion that the subcontractors systems engineers need not be involved in the RE&M process at the top level.
v. There is also a suggestion that subcontractor systems engineers should have access to the higher level requirements in order to understand the flow down/traceability of requirements that impact them. An understanding of higher level requirements enables a clearer understanding of the lower level requirements that are flowed down to subcontractors.

3. **Requirements engineering & management at program management level**

i. The respondents who are not in management positions are unable to answer this question.
ii. There was a system set in place that management were not to get involved with technical issues and RE&M processes are usually technical

issues. The reason was a possibility of conflict between safety and budgeting. If the RE&M team stated that ... 'we can't meet these requirements by the deadline'... The information was not thrown away by management who were more interested in the deadline. There was a set up in which an independent and knowledgeable leader was responsible for resolving conflicts that arose between technical requirements issues and budget concerns.

iii. Firm program management was required when it came to baseline management. i.e. sticking to a contractual baseline and not allowing changes and/or additional requirements to slip in without due process.

iv. Program management teams need to fully understand the RE&M process so that when they propose program schedules and program statements of work, they take the RE&M process into account.

4. Requirements engineering & management with suppliers and subcontractors

i. Not all the engineering teams were involved in the selection of suppliers and subcontractors i.e. the integration engineering team was not involved in the selection of suppliers and subcontractors.

ii. Not all respondents were involved or informed with regards to the selection of suppliers and subcontractors.

iii. At some stages the main contractor and client were not confident of subcontractors being managed.

iv. There were joint configuration control board (CCB) meetings held with subcontractors to discuss issues related to RE&M process.

v. In some cases off-the shelf items were used and suppliers were sub-contracted to fulfil and perform missing environmental requirements.

5. **Interdepartmental requirements engineering & management coordination**

i. With regards to interdepartmental coordination, requirements were put out to the respective departments e.g. systems engineering division sent a requirements document to the software engineering division, similar process as sending a requirements document to a subcontractor.

ii. If you consider systems engineering to be a contractor defining requirements and software engineering had to implement those requirements, then software engineer is a subcontractor. Similarly integration engineering is also a subcontractor

iii. Systems and software engineering cooperated in defining changes to the Detailed Functional Specification (DFS).

iv. Systems engineers were involved in the software testing process.

v. There was a review process between the departments.

vi. There is a lack of inter departmental coordination with regards to the planning process i.e. systems engineering dictates to software engineering the work to be done and the time allocated for the work. There is no consultation process.

vii. One respondent noted that even though a subcontracting division is part of the organisation, it is critical to ensure that the requirements are properly allocated and flowed down and there should be establishment of a formal baseline as is the case with an external subcontractor.

6. **Use of Requirements engineering & management tools**

i. Requirements were managed manually by use of spread sheets and databases.

ii. Manual management of requirements took a lot of time and effort, it was a nightmare!

iii. For smaller programs, a formal tool is not essential. However, for complex systems, it is critical.

iv. Use of a Man Machine Interface (MMI) tool is even better. MMI tools are visual. The pilot and the systems engineer use this tool in discussion of symbology, layout and functionality.

v. Lack of RE&M tools has greatly limited the RE&M process, capturing and maintaining requirements becomes very difficult as the project progresses

vi. Requirements management tool (DOORs) licence costs were considered too costly initially. But with current projects, the organisation is slowly integrating and buying DOORs licences.

7. Requirements engineering & management problems experienced [biggest mistakes]

i. Decisions on selection of equipment are led by what is available and not the requirements document. It is often easier to source off-the-shelf equipment that is already qualified. This problem can be solved if more time is allocated, during the early phases, to sourcing ultimate solutions.

ii. Inexperienced engineers. RE&M engineers are sometimes inexperienced and hence do not understand the impact of a requirement.

iii. Ambiguity in requirements. RE&M engineers may read a requirement which is ambiguous and they don't request that requirement to be clarified and when it comes to requirements qualification it's impossible to prove that requirement because it is ambiguous.

iv. Lack of a proper RE&M tool. This led to critical requirements being missed or left out and resulted in plenty of additional work later on.

v. Requirements testing took place much later in the project than it should have. The result was integration and test engineers were '…playing catch-up…'

vi. Under estimating the effort involved with traceability.

vii. Under estimating the importance of requirements traceability

viii. Improper establishment of a sound baseline that supported lower level structures.

ix. Automation vs. Manual. The LIFT project initially started with automated processes but later moved into manual processes. The result a huge amount of work overload.

8. Requirements engineering & management positives [success stories]

i. Skilled and committed team. The LIFT Hawk program contained a group of skilled and committed engineers.

ii. Communication. There was good communication within the LIFT program. Good communication assisted in requirements resolution. There were meetings between the RE&M engineering team and the end users to resolve ambiguities.

iii. Good/Strong management. The program manager was in good control of the program. There were schedules and plans, and at any time milestones and deliverables were communicated to the engineering team.

iv. Iterative approach. With each iteration of development, the team learnt from previous mistakes... "...So If you look at the process in 0C4, going into it, we had a much clearer and defined plan and methodology of how we would do each piece exactly because we'd gone through it those 3 times (OC1, OC2 & OC3)..."

9. Requirements engineering & management lessons learnt and what can be done to improve the process

i. More integration of teams / teams working in parallel. Systems engineers and integration engineers should work together right from the start. As systems engineers write requirements documents, integration engineers should in parallel write test documents. This would prevent the integration team from lagging behind in testing documentation and activities.

ii. Traceability. Traceability must be managed right from the start. Playing 'catch up' on traceability is disastrous.

iii. Improved negotiation process. Negotiation over time scales is essential. Time lines and deadlines should not be handed down from the top (Main contractor or Management teams) without negotiation and discussion.

iv. Upfront agreement on a structured RE&M process. It is critical to spend enough time upfront to ensure a sound RE&M process. Trying to retrofit sound RE&M processes later in the development is disastrous.

v. Regular group discussions amongst engineers within the program. Every RE&M engineer has their own idea on how to define requirements. Group discussions aid in getting consensus and consistency in the RE&M process.

vi. Agreement on traceability management at different levels and knowledge of applicable specification or documents.

vii. An improved requirements review process is essential. Use of MMIs is very useful in the requirements review between RE&M engineers and end users.

viii. Improve quality of the requirements. More time needs to be spent on generating better quality requirements i.e. less ambiguity.

10. Requirements engineering & management training? Should engineers attend such courses? Discuss?

i. Yes. The younger inexperienced engineers need to be trained on the RE&M processes. There also needs to be a balance between training, experience and exposure.

ii. Yes. If there are courses that can add value to the engineers, then the engineers should attend these courses.

iii. Yes. These training are very important, especially when one is a requirements engineer and has to write requirements related documents and specifications. Requirements engineering is all about requirements, writing requirements, deriving requirements, managing requirements, designing a system to fulfil requirements.

iv. No. There was no value gained from RE&M training that was carried out.

v. Not really. RE&M courses are passively taught, whereby the engineers sit and listen to a lecturer. Rather, experience through practice and applying the basic RE&M principles is key.

vi. Training on RE&M tools is also important.

vii. Different kinds of training should be considered. External RE&M processes, internal company processes and also RE&M tools training.

11. Are project completion delays, missed milestones, dissatisfied customers and increased costs attributed to poor requirements engineering & management?

i. Yes. Poor RE&M could lead to project completion delays, missed milestones, dissatisfied customers and increased costs.

ii. There are also external factors that lead to the above e.g. A delay in responses from a main contractor or subcontractor would lead to delays in deliveries.

iii. With a technically strong program manager, project completion delays, missed milestones, dissatisfied customers and increased costs can be avoided

iv. Project delays are definitely influenced by poor RE&M.

v. There are unknown factors that creep in and cause project completion delays, missed milestones, dissatisfied customers and increased costs. E.g. skilled RE&M engineers leave for better ‘pastures’, employment of inexperienced RE&M engineers.

vi. Poorly written requirements documents definitely contribute to project completion delays, missed milestones, dissatisfied customers and increased costs.

vii. A badly written contracting model with strict time constraints often leads to poor requirements being passed through hence leading to project completion delays, missed milestones, dissatisfied customers and increased costs.

viii. Cash flow problems. When the organisation has a cash flow problem it will sign contracts with unrealistic time scales and expectations in order to realises cash flow. This lead to project completion delays, missed milestones, dissatisfied customers and increased costs.

ix. Poor interpretation of requirements by main contractor, subcontractor and end user results in re-work that leads to project completion delays, missed milestones, dissatisfied customers and increased costs.

x. Lack of feedback and communications, by main contractor, subcontractor and end user, in the RE&M leads to project completion delays, missed milestones, dissatisfied customers and increased costs.

xi. No. The RE&M process in the Lift Hawk Program was well done.

xii. Proper reviews and clarity in allocation of RE&M tasks and responsibilities would decrease effect of project completion delays, missed milestones, dissatisfied customers and increased costs.

xiii. When client is not happy with the end product, re-work needs to be done and the result is to project completion delays, missed milestones and increased costs.

xiv. Continuous reviews with end users and clients so that clients continuously influence the perception of a requirement, will results in timely completion of projects and satisfied customers.

5.3 Analysis of Vulture Case Study

1. Your function/role in this project

The response to this question addresses the fact that respondents are all experienced engineers. Respondent performed various engineering functions within the aerospace and defence engineering projects. These were systems engineering management, and program management. Respondents were chosen based on their expertise and years of experience

2. **For this project, discuss main contractor's role, government's role or sub contractor's role w.r.t Requirements engineering & management**

Within the Vulture program, the main contractor was Organisation A, the main client was the South Africa National Defence Force (SANDF) artillery formation. Armscor was the government body acting on behalf of and together with the client. The following points were observed:

i. Within the Vulture program, the main client sent out Requests for Proposals (RFPs) to industry based on the requirements. Industry came up with proposals based on the requirements. In other words, the main client together with the user provided a set of requirements (user requirements specification) and industry responded with a proposal.

3. **Requirements engineering & management at program management level**

i. Program management was responsible for the technical performance of the system, the financial control as well as the schedule in terms of deliverables. The engineering team performed the technical work and reported to the program manager w.r.t the engineering process.

4. **Requirements engineering & management with suppliers and subcontractors**

i. The process of designing the system was carried out closely with subcontractors.

ii. There were not many off the shelf products that met the requirements, hence equipment was developed from scratch.

iii. Authority was given to Organisation A to decide whether non-compliance was acceptable. When non-compliance was acceptable, motivation was needed. This points to the fact that some requirements from the client and main contractor were ridiculous and not laterally flexible.

5. **Interdepartmental requirements engineering & management coordination**

i. Detailed functional specifications (DFSs) were written in enough detail before hand over to the software engineering department to implement. Software engineering would then use the DFSs to write lower level Software Requirements Specifications (SRSs).

ii. Simulations were heavily used.

iii. The program manager would interact at management level with respective divisional managers to facilitate support of other division.

6. **Use of Requirements engineering & management tools**

i. RE&M was done manually, no specific tools were used.

ii. There are some in-house RE&M tools developed and used by the software engineering division. There were no company-wide RE&M tools used.

7. **Requirements engineering & management problems experienced [biggest mistakes]**

i. Not enough time was allocated to systems engineering activities at the beginning of the program before establishing the functional baseline and allocated baseline. The Preliminary Design Review (PDR) is scheduled far too soon in the process because the organisation wants to realise cash flow. The PDR is usually an important milestone that attracts a lot of income.

ii. There was a lack of RE&M tools.

8. **Requirements engineering & management positives [success stories]**
   i. Close interaction between systems engineers and software engineer was a huge success
   ii. Continuity. Requirements traceability was done manually successfully. The only reason it was successful was because there was continuity. The key systems engineers were involved throughout the whole project.

9. **Requirements engineering & management lessons learnt and what can be done to improve the process**
   i. Requirements traceability from the start of the project is critical. It took a huge effort to get requirements traceability much later in the project.
   ii. Less development of all components used in the system. "Design and manufacture of UAOS airframes is a huge task and a huge component of costing. So rather consider buying COTS items and slightly modify or adapt them"

10. **Requirements engineering & management training? Should engineers attend such courses? Discuss?**
    i. Yes. Basic RE&M courses to get the idea and processes in place should be taught. The rest should be learnt through application.
    ii. Yes. Enough time should be set to get engineers trained on the RE&M processes. "There is not enough time set out to get people trained in areas where they could improve the processes to save time scales" .

11. **Are project completion delays, missed milestones, dissatisfied customers and increased costs attributed to poor Requirements engineering & management?**
    i. Missed milestones are caused by scheduling design reviews ,e.g. PDR, too soon in the systems engineering process within the project.

ii. Proper baselining during product development is critical.
iii. A good idea is not proceeding until all TBDs are resolved. This can be done by allocating majority of the resources to solving TBDs.
iv. New requirements that creep in later on in the process and result in delays leads to dissatisfied and disgruntled customers. This also lead to increased costs.
v. Changing requirements and quantities lead to project completion delays, missed milestones, dissatisfied customers and increased costs.
vi. Change in the scope of work lead to project completion delays, missed milestones, dissatisfied customers and increased costs.

5.4 Comparison of Lift Hawk Case Study and Vulture Case Studies

1. Your function/role in this project

In comparing the two case studies, all respondents perform various engineering roles within the aerospace and defence sector. The engineers are well experienced in their fields. Barenbach (2008) states that RE&M engineers need to be trained and experienced before they can create high quality specifications. Barenbach (2008) further emphasises that one of the key factors necessary for successful RE&M in complex project development is that engineers involved in the RE&M process should be trained and experienced

2. For this project, discuss main contractor's role, government's role or sub contractor's role w.r.t Requirements engineering & management

There are two opposing responses. The one emphasizes the need for subcontractors to have access to the higher level requirements in order to understand the flow down/traceability of requirements. The other is that subcontractors need not be involved in the RE&M process at the top level. In the Vulture program, the main client sent out Requests for Proposals (RFPs) to industry based on the requirements. Industry came up with proposals based on the requirements. In other words, the main client together with the user provided a set of requirements (user requirements specification) and industry responded with a proposal. Incose systems engineering handbook (Incose 2008) states that establishing good relationships and open communication between requirements engineers and stakeholders is critical. It is helpful when negotiations begin to refine and clarify the set of requirements. Incose systems engineering handbook (Incose 2008) further emphasizes that a joint team responsible for the requirements should be established and utilised. This joint team is a small group of people who are experienced and knowledgeable on the requirements and have the authority to make requirements decision on behalf of the project. All stakeholders need to be represented in this team

3. Requirements engineering & management at program management level

There is an emphasis on program management to fully understand the RE&M process. An interesting point raised is that program management should not be involved in technical RE&M process issues as there is a possibility of conflict between safety and budgeting. Program management should focus on financial control as well as schedule of deliverables. Olson (2007) states that use of a formal configuration management process to place requirements under formal baseline control is necessary for improving the requirements process. Young (2001) states that performing verification and validation planning early in the development can improve the quality of the requirements and also control costs and risks. Hood *et al* (2008) states that for project planning, the customer should allocate a budget of time and money before the bidding even starts, in order to produce good requirements specification that will serve as a basis for the call for bids.

4. Requirements engineering & management with suppliers and subcontractors

In the Lift Hawk program, not all engineering teams were involved in the selection of suppliers and subcontractors. There were however joint configuration control board (CCB) meetings held with subcontractors to discuss issues related to RE&M process. In the Vulture case studies, the process of designing the system was carried out closely with subcontractors. In the Lift Hawk case program, off-the-shelf items were purchased and suppliers were sub-contracted to fulfil missing environmental requirements. In the Vulture program, there were not many off the shelf products that met the requirements, hence equipment was developed from scratch. In the Vulture program, authority was given to Organisation A to decide whether non-compliance was acceptable. When non-compliance was acceptable, motivation was needed. Hood *et al* (2008) states that user requirements should be specified in ways that do not contain any unwarranted restrictions or solutions due to technology or otherwise. Furthermore RE&M can support the purchasing department with creation of the user requirements specification, which is then sent to all prospective suppliers. In addition it is expected that the suppliers create a target specification where they give details of how they propose to solve the problem. Young (2001) states that effective communication and coordination are fundamental to project success. Proactive steps should be taken to promote effective communication. A project CCB can provide a mechanism for close and continuous communication and coordination of all the groups supporting a project

5. **Interdepartmental requirements engineering & management coordination**

The emphasis here is on that fact that even though a subcontracting division is part of the organisation, it is critical to ensure that the requirements are properly allocated and flowed down and there should be establishment of a formal baseline as is the case with an external subcontractor. In both programs there was close interaction amongst the various engineering teams e.g. the systems engineers were involved in the software testing process. There was however a lack coordination w.r.t time allocation for work. There was no consultation and systems engineering team imposed time limits to the software engineering team. Young (2001) states that effective communication and coordination are fundamental to project success. Proactive steps should be taken to promote effective communication. A project Configuration Control Board (CCB) can provide a mechanism for close and continuous communication and coordination of all the groups supporting a project.

6. **Use of Requirements engineering & management tools**

In both programs RM process was performed manually. The lack of RE& tools greatly limited the RE&M process. Additional effort and time was needed for requirements management. Sparrius (2009) states that in order to keep track of the changes and to control and categorize the requirements, requirements management tools are necessary. A requirement management tool that augments a decision database should be accessible to and usable by all technical personnel on the project. Inputs to the database include draft specifications, comments, approvals, status data, change data, and requests. The tool should be able to generate the following directly from the database: Requirements documents with automatically generated project unique identifiers; requirements traceability matrices; requirements verification cross reference matrices; lists of TBDs and TBCs; specifications; and requirements metrics e.g. Requirements stability. The tool should have configuration management capability to provide traceability of requirement changes, and to ensure that only changes that are properly authorized are made

7. Requirements engineering & management problems experienced [biggest mistakes]

A number of factors were considered the biggest mistakes w.r.t RE&M. These include, decision on selection of supplier equipment, people inexperience, ambiguity in requirements, lack of proper RE&M tools, under estimating the effort required for and importance of requirements traceability, not allocation enough time for critical systems engineering activities. Barenbach (2008) states that requirements engineers typically need significant training, both classroom and on the job, before they can create high-quality specifications. Furthermore, one of the key factors necessary for successful R&M in complex projects is that RE&M engineers are well trained and experienced. Young (2001) and Sparrius (2009) emphasise that unambiguity is a criteria for a good requirement. Every requirement shall be stated in such a manner that the likelihood of misinterpretation and misunderstanding by a non-expert is negligible. Danger signs include vagueness about the type of user and generalization words such as usually, generally, often, normally, typically (Sparrius 2009). Ambiguous or poorly worded writing can lead to serious misunderstanding and needless rework. Specifications should include a list of acronyms and a glossary of terms to improve clarity (Young 2001).Sparrius (2009) emphasises the need for a RM tool. Olson (2007), states that one of the strategies that greatly aides in improving the RE&M process is use of formal configuration management to place requirements under formal baseline control

8. **Requirements engineering & management positives [success stories]**

With both Lift Hawk and Vulture programs the following were considered positive and successful. Skilled, experienced and committed teams, good communication, strong management, iterative approach to the development, close interaction between the various engineering teams as well as continuity of key team engineers. Barenbach states that the core project team should be full time and should report into a single chain of command. Incose systems engineering handbook (Incose 2008) states that a Joint team responsible for the requirements should be established and utilised. This joint team is a small group of people who are experienced and knowledgeable on the requirements and have the authority to make requirements decision on behalf of the project. All stakeholders need to be represented in this team. Incose systems engineering handbook (Incose 2008) further emphasizes that establishing good relationships and open communication between requirements engineers and stakeholders in critical. It is helpful when negotiations begin to refine and clarify the set of requirements. Young (2001) states that one effective requirements practice that will reduce costs, improve quality of work products and increase customer satisfaction is iterating systems requirements and architecture repeatedly.

9. **Requirements engineering & management lessons learnt and what can be done to improve the process**

When it comes to improving the RE&M process the following are considered:

a) There should be more effort put into integrating teams i.e. engineering teams should work in parallel.
b) Traceability must be managed from the start of the project.
c) Negotiation over time scales with main contractor, subcontractor and client should be carefully and thoughtfully done.

d) It is critical to spend enough time upfront to ensure a sound RE&M process. Trying to retrofit sound RE&M processes later in the development is disastrous.
e) There should be regular group discussions amongst engineers within a program in order to get consensus and consistency during the RE&M process.
f) There needs to be an emphasis on a proper requirements review process with all stakeholders.
g) More time needs to be spent on generating better quality of requirements.
h) Decisions on whether to buy COTS items or to develop equipment from the ground up need to be taken carefully.

Traceability is stated as a complex, overwhelming task that is critical to the successful completion of a project. Barenbach (2008) states that a distinctive and costly blunder on projects is to wait until the analyses are needed before employing a traceability strategy. Incose systems engineering handbook (Incose 2008) states that traceability should commence from the start of the project. Young (2001) states that traceability is one of the criteria of a good requirement. The origin (source) of the requirement must be known and the requirement can be referenced (located) throughout the system.

10. Requirements engineering & management training? Should engineers attend such courses? Discuss?

There is agreement from both programs that RE&M training needs to take place. A balance between training, experience and exposure needs to be maintained. After basic training, additional RE&M processes needs to be learnt through application. Organisations should set enough time within the works schedule for the training process. Barenbach (2008) states that requirements engineers typically need significant training, both classroom and on the job, before they can create high-quality specifications. Barenbach (2008) further states that one of the key factors necessary for successful

R&M in complex projects is RE&M engineers are well trained and experienced.

11. **Are project completion delays, missed milestones, dissatisfied customers and increased costs attributed to poor Requirements engineering & management?**

The unanimous answer is that yes, indeed project completion delays, missed milestones, dissatisfied customers and increased costs attribute to poor RE&M. In addition there are other factors outside RE&M process that lead to project completion delays, missed milestones, dissatisfied customers and increased costs. These include:

- Delay in response from main contractor or subcontractor would lead to delay in deliveries hence project completion delays, missed milestones, dissatisfied customers.
- With a technically strong program manager project completion delays, missed milestones, dissatisfied customers and increased costs can be avoided.
- Unknown or unexpected factors such as skilled RE&M engineers leaving for 'better pastures' and employment of inexperienced RE&M engineers can cause project completion delays, missed milestones, dissatisfied customers and increased costs
- A badly written contracting model with strict time constraints often leads to poor requirements being passed through hence leading to project completion delays, missed milestones, dissatisfied customers and increased costs.
- When the organisation has a cash flow problem it will sign contracts with unrealistic time scales and expectations in order to realises cash flow. This lead to project completion delays, missed milestones, dissatisfied customers and increased costs.

- Proper reviews and clarity in allocation of RE&M tasks and responsibilities would decrease effect of project completion delays, missed milestones, dissatisfied customers and increased costs.
- Continuous reviews and with end users and clients so that clients continuously influence the perception of a requirement will results in timely completion of projects and satisfied customers.
- Change in the scope of work lead to project completion delays, missed milestones, dissatisfied customers and increased costs.

5.5 Learning Principles from SA Case Studies

Learning Principle-1: Engineering decisions not led by what COTS equipment are available but by requirements

RE&M team could be tempted to sacrifice some requirements for the sake of easily available COTS equipment. Often times a COTS line replaceable unit that meets most of the requirements is selected because it would require less effort than developing a product from the ground up. It is important for the RE&M team to allocate enough time and resources in making the decision on whether to use a COTS item or to develop the unit from the ground up.

Learning Principle-2: Time allocated to Systems Engineering Activities

The organisations needs to thoroughly and intently allocate time to various tasks within the systems engineering process, whether it be writing of requirements, sourcing of COTS equipment, or review meetings.

Learning Principle-3: Closer working relationship between systems engineers and integration engineers

During the early phases of the LIFT Hawk program, the systems engineering team and the integration engineering team worked separately. The systems engineering team completed their systems engineering work before flowing down specifications and requirements to the integration engineering team. The result was that integration team lagged with integration activities such as acceptance testing activities. Systems engineering and Integration engineering teams should work in parallel during the RE&M stages. This is so that as the systems engineering team write out specifications and requirements documents, the integration engineering team interact closely in determining the appropriate test methods and procedures for those requirements.

Learning Principle-4: Strong leadership and skilled, experienced and well trained engineers

The core RE&M engineers were well trained and experienced in the systems engineering field. The team was committed and understood the RE&M process. The program manager on the LIFT HAWK program was well experienced and a strong leader. This was vital to team during times of uncertainty with respect to baseline agreements, commitments, client complaints and stakeholder disagreements.

Learning Principle-5: Program documents and specifications accessibility

All specifications and documents (high level specifications, component specifications, equipment specification, customer furnished equipment specifications, supplier specifications) must be stored and be readily available and accessible to all engineers. There should be a common network drive for these specifications and documents to be accessed. The specifications must be grouped according to specific baselines. Configuration control team should be involved in setting up a database and keeping track of all program documentation and specifications.

Learning Principle-6: Requirements Traceability

A requirements traceability mechanism should be defined and implemented from the start of the project. This should be capable of ensuring and demonstrating adequate user requirements capture, supporting the identification and addition of derived requirements, confirming complete flow-down of requirements into lower level specifications and subcontracts. Requirements should be broken down to as low a level as possible to avoid ambiguity when it comes to verification. This mechanism should also support the requirements compliance documentation process such that reports on the compliance status can be complied. It is critical to ensure that each top level requirement is fully flowed down and fully satisfied by lower level specifications. It is too late at the end of the verification process to discover that the lower level requirement does not adequately cover off the top level requirement. RE&M engineers should continually check to ensure that evidence gained at the lower level will actually satisfy (or help to satisfy) the top level requirements from which they were derived.

Learning Principle-7: Requirements Verification

Careful consideration should be given upfront to the verification methods that are defined for each requirement. Assumptions should not be made (or should be stated). Flight tests should not be performed without considering the implications and feasibility.

Learning Principle-8: Configuration of minutes of formal technical reviews, correspondence with stakeholders

Minutes of formal technical reviews (requirements reviews, design reviews, technical progress reviews etc) and document reviews should be configured to ensure traceability and availability. A mechanism needs to be put in place whereby actions arising from these formal technical reviews are captured and tracked. A reporting mechanism should be implemented in order to get the status of actions at a point in time as well as the history of closed actions and the means by which closure was agreed. All official correspondence with stakeholders and actions arising from these correspondence should be recorded. The source of the action should be traceable and closure evidence should be entered against each action when the action is closed. Regular action log meetings should be held to ensure that actions are being addressed as well as to identify outstanding actions and areas of risk.

Learning Principle-9: Testing activities

Testing performed at all levels (systems engineering, integration engineering, flight testing etc) should be traceable to requirements. Test results therefore should also be traceable to requirements. This will ease the compilation of compliance evidence. All tests performed whether relevant or irrelevant should always be documented. Too often tests have had to be re-done because earlier tests were not document. This re-testing is often costly.

Learning Principle-10: Requirements driven approach

Towards the end of the program it is normal to focus on addressing the problems and certain failures or complaints from stakeholders. The RE&M team must not lose sight of the requirements that need to be closed off. When raising fault reports, addressing complaints and questions from stakeholders; RE&M engineers should always try to link these to specific requirements. Defining of tests should also be done with a view of closing a requirement.

Learning Principle-11: Requirements changes

Check lists on requirements changes involving all of the functional, physical, logistic and support aspects of the product (as much as can be identified) should be defined. The design process should include a check list that will aid in ensuring that the impact of a change on memory, processing power and bus loading is assessed in the early design stages.

Learning Principle-12: Stakeholder should be involved in proto type tests that confirm and clarify requirements

More time should be allocated early in the development to allow the customer to be involved in prototyping the design to confirm and clarify the requirements are being met before committing to detailed design. These sessions should be formally minuted.

Learning Principle-13: Requirements Verification Plans

Requirements verification plan to close the requirements should be generated and agreed upon as part of the contract and not post contract.

Learning Principle-14: Communication within the team

Communication is critical to the success of a program. There was good communication within the Systems engineering team of the LIFT HAWK program. The good communications assisted in the requirements resolution process.

Learning Principle-15: Proper requirements management tools

In large and complex systems engineering projects, a good requirements management tool is a critical. Lack of an adequate requirements management tool can greatly increased the systems engineering workload and timescales. Mistakes are discovered much later when requirements are managed manually.

Learning Principle-16: RE&M Training

Requirements related courses for the systems engineering team involved in writing requirements documents and specifications is essential. Key topics include writing requirements, deriving requirements, managing requirements, designing a system to fulfil requirements.

Learning Principle-17: Iterative RE&M process

With each RE&M process iteration of the continued project development, lessons were learnt and improvements were made in the subsequent stages.

Learning Principle-18: Proper and consistent RE&M review meetings

It is critical to ensure that that proper reviews are performed specifically from the client or main contractor down to us subcontractors in terms of the interpretation, ensuring there is a full definition of the requirements at all levels which forms the contractual baseline and that there is agreement between the main contractor and the various subcontractors.

Learning Principle-19: Spend enough time upfront to ensure that a sound RE&M process is established

Systems engineering team should right upfront agree on a structured RE&M process and get into agreement on what and how the process will be followed. A consolidated view is essential in addressing RE&M process all through the project.

Learning Principle-20: There should be regular Internal discussions and work sessions amongst systems engineering teams

Learning Principle-21: Main contractor and subcontractor visibility

There should be an increased visibility with respect to RE&M activities amongst the various stakeholders, subcontractors, and suppliers. Particularly, the main contractor requirements engineering activities should be visible and flow down to the various subcontractor.

Learning Principle-22: Management should not be involved in RE&M technical activities

RE&M should be wholly delegated to the systems engineering team. There is a potential conflict between safety and budgeting if management is involved in technical RE&M activities. For example, if the systems engineering team state that '...we can't meet these requirements by this deadline...' that information shouldn't just be thrown away by management who are more interested in the deadline. There should a independent program leader who would resolve cases of conflict between technical RE&M activities and budgeting activities.

Learning Principle-23: Not enough time is allocated to systems engineering activities at the beginning of the program

Enough time needs to be allocated to systems engineering activities prior to the Preliminary Design Review (PDR). Baseline management (RBL and FBL) should be factored into this decision. PDRs are usually scheduled far too soon in the process in a bid to realise cash flow, this is because PDR is usually an important milestone that attracts plenty of income. The consequence of PDR scheduled earlier than necessary is that the system design evolves a lot more after the PDR.

Learning Principle-24: Project continuity and continuity of key team members

The core team members (systems engineers and integration engineers) of the Vulture program were involved throughout the entire project. The core team members were present from the start to the end of the project. Requirements traceability and management was performed manually (without use of a requirements management tool) during the entire project. This was a success mainly because the core team members were present to recall decisions made, answer questions and solve problems throughout all phases of the project. If there had been no continuity, requirements traceability and management would have been a failure. For large projects automated requirements traceability and management is critical.

Learning Principle-25: Training

Training of team members with regards to systems engineering process is imperative. Project and program managers should also initiate training in areas of process improvement that would save time.

5.6 Comparison of SA Case Studies and US DOD Case Studies

In this section, the learning principles of the SA case studies are compared to those of the US DOD case studies. In comparing the SA case studies and the of the US DOD case studies. The following commonalities were observed:

i. Development and documenting of requirements i.e. RE&M process should be a coordinated effort involving all stakeholders from government and industry.

ii. It is critical to ensure that that proper reviews are performed specifically from the client or main contractor down to us subcontractors in terms of the interpretation, ensuring there is a full definition of the requirements at all levels which forms the contractual baseline and that there is agreement between the main contractor and the various subcontractors.

iii. A requirements traceability mechanism should be defined and implemented from the start of the project. This should be capable of ensuring and demonstrating adequate user requirements capture, supporting the identification and addition of derived requirements, confirming complete flow-down of requirements into lower level specifications and subcontracts. Requirements should be decomposed to as low a level as possible to avoid ambiguity when it comes to verification. This mechanism should also support the requirements compliance documentation process such that reports on the compliance status can be complied. It is critical to ensure that each top level requirement is fully flowed down and fully satisfied by lower level specifications.

iv. Every requirement must have a verification method.

v. RE&M team should right upfront agree on a structured RE&M process and get into agreement on what and how the process will be followed. A consolidated view is essential in addressing RE&M process all through the project

vi. The organisations needs to thoroughly and intently allocate time to various tasks within the systems engineering process, whether it be writing of requirements, sourcing of COTS equipment, or review meetings

6. CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusion to the research including the final evaluation of the research objectives which were met as well as recommendations for future research questions arising from the research.

6.1 Conclusion

In recent years organisations are realising that methods and process of RE&M are indispensable for cost saving, keeping up with timelines and deadlines, meeting target dates and increasing customer satisfaction. According to surveys conducted engineering employees indicated that the majority of problems related to requirements were inability to track changes in requirements; difficulty in writing requirements; disorganised requirements; a large number of sources for the requirements; many different types of requirements at different levels of detail; a large number of requirements that often becomes unmanageable and uncontrollable

The research aim was to investigate RE&M processes and their effect on projects within the South African aerospace and defence sector i.e. how do RE&M practices affect projects within the South African aerospace and defence sector? Are project completion delays, missed milestones, dissatisfied customers and increased costs attributed to poor RE&M? What needs to be done to improve RE&M processes within complex systems development in South African aerospace and defence sector?

From the research conducted it can be deduced that poor RE&M practices affect projects within the South African aerospace and defence sector. Poor RE&M practises affect areas of supplier selection, under estimating effort required for requirements traceability, as well as incorrect allocation of time for critical systems engineering activities. Project completion delays, missed milestones, dissatisfied customers and increased costs attribute to poor RE&M. In addition there are other factors outside RE&M process that lead to project completion delays, missed milestones, dissatisfied customers and increased costs. To improve the RE&M processes within complex systems development in South African aerospace and defence sector, RE&M process should be a coordinated effort involving all stakeholders from government to industry; it is critical to ensure that that proper reviews are performed; a requirements traceability mechanism should be defined and implemented from the start of the project; The organisations needs to thoroughly and intently allocate time to various tasks within the systems engineering process. The research questions are therefore answered.

The qualitative nature of this study means that data of greater depth was gathered from a small sample of the population. Twelve persons were selected for interviews. The respondents were chosen based on their expertise and years of experience in the area of RE&M. The respondents occupied systems engineering, integration engineering, project management and program management positions. Due to proprietary information constrains, the research was limited to systems engineers, integration engineers, project managers and program managers within one organisation

The strength of this research is that it shows that improvements in RE&M processes can lead to drastic improvements within entire complex systems development projects within South African aerospace and defence sector. Improvements in RE&M process will lead to reduced overspending, customer satisfaction, on time completion of projects as well as proper management of milestones

6.2 Recommendations for Future Work

Research on the following topics would be beneficial in continuing to improve complex system development process in South African aerospace and defence sector

- Research the other stages in system life cycle of complex systems development within South African aerospace and defence sector.
- Benchmarking process used in complex system development within South African aerospace and defence sector.

The most important recommendation is for research of complex systems development within other organisations in the South African aerospace and defence sector. This would provide more comprehensive and reliable information within the South African aerospace and defence sector.

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APPENDIX A1: CASE STUDY QUESTIONNAIRE

Investigating Requirements Engineering and Requirements Management Processes in South African Aerospace and Defence Industry Projects

Project Name:
Main Contractor:
Subcontractors:

1. Your function/role in this project

2. For this project, discuss main contractor's role, government's role or sub contractor's role w.r.t Requirements engineering & management

3. Requirements engineering & management at program management level

4. Requirements engineering & management with suppliers and subcontractors

5. Interdepartmental requirements engineering & management coordination

6. Use of Requirements engineering & management tools

7. Requirements engineering & management problems experienced [biggest mistakes]

8. Requirements engineering & management positives [success stories]

9. Requirements engineering & management lessons learnt and what can be done to improve the process

10. Requirements engineering & management training? Should engineers attend such courses? Discuss?

11. Are project completion delays, missed milestones, dissatisfied customers and increased costs attributed to poor Requirements engineering & management?

APPENDIX A2: INTERVIEWEE RESPONSES

Appendix A gives full transcripts from interviews conducted. The format of each interview are presented below

Project1:	**Lead In Fighter Trainer (LIFT) Hawk** LIFT Hawk Project, Armscor the government body acting on behalf of the SANDF(airforce in this case) in contracting Main contractor is BAE systems, Organisation A main subcontractor for the entire avionic system
Researcher Question1:	**Your function/role in this project**
Respondent1	Part of the integration team; Integration engineer. As part of the team we built test benches, we wrote test procedures and at the end made sure that the requirements were met at system level testing on the integration bench. Furthermore we also support flight testing, and even went through till the production phase, we also accept production sets for delivery.
Respondent2	LIFT OC4 Electronic Warfare (EW) Program was to install an Instantaneous Frequency Measurement (IFM) module. So there we did. But the only thing that that module did was provide frequency.So the requirements were purely environmental. So I don't know if that's a good example
Respondent3	Integration Engineer. I was part of the Integration team Requirements were given unto me as far as requirements

	are concerned I wasn't involved in requirements formulation and management myself but during the OC4 phase in particular I had more of a view as to what was going on in the process It was more transparent to me then, than it was during the initial phases of the LIFT program. Because when I got into the program, the POD was already written, the B1 spec was already written and the requirements were already formulated to quite a large extent. Requirements formulation and management is primarily a systems engineering task
Respondent4	Role: System engineering Function: System engineering and data analyst
Respondent5	On LIFT since 2003 more or less, I took over the role as Safety manager, involved in all the safety liaison with the main contractor as well as responsible for the safety analysis together with one or two other people and getting all the results and the mitigation and the final argument in place For the last 3 years or so once the safety has reached the baseline, I was involved in Systems engineering, responsible for systems engineering on the project including some of the safety activities so there was a release to service (RTS) baseline and following that I took over as systems engineer including the safety change;

	system change safety analysis
Respondent6	I was a program manager on the program
Respondent7	Currently I am the technical manger of Hawk so that basically means coordinating all the technical activities All the technical guys then report to me in terms of Hawk work
Researcher Question2	**For this project, discuss main contractor's role,government's role or sub contractor's rolew.r.t Requirements engineering & management**
Respondent1	Get this information from a senior engineer or program manager
Respondent2	Speak to the program manager
Respondent3	As far as OC4 is concerned, the main contractor being BAE systems Am not so involved in the requirements formulation as far as I could gather was more between us (Organisation A) being the subcontractor and the customer The Airforce is the government body. If you consider the government to be the airforce then yes In OC4, the air force brought out the requirements There was some requirements clarification where the air force were unhappy with what they had, they didn't feel like the requirements were correctly implemented

	Some requirements were clarified and then new requirements were raised Initially when the POD was being written, the Airforce (client) was quite/intensively involved and also BAE systems (main contractor)
Respondent4	it's a contracted baseline What each of the roles are For this project specifically the main contractor being BAE systems had quite a large role in the requirements management Government's role I think was very small However on the project we as subcontractors had very little visibility (at my level i.e. system engineering) between what went on between the main contractor and the government Me sitting as systems engineer at the subcontractor level doesn't have much visibility Visibility is a good idea? I don't think it's necessary that's just how it is If Armscor have requirements that go to BAE and then they flow down to us, do I (systems engineer) need to know what the discussion between BAE and armscor are? US Airforce case study:The idea of coordination between

	the government office, main contractor, end user, researchers. They had work groups that met to write down and discuss requirements, exchange information and ideas All of that is true but we (Organisation A) are sitting beneath all of that, we (Organisation A) are a subcontractor So there is the end user (aiforce/SAAF) the government body (armscor) and the main contractor (BAE) Some of the duties of requirements engineering & management at that level was delegated down to us, we did have some interaction with the end user (airforce/ SAAF). But that which you are referencing to all sits above the subcontractor that we (Organisation A) are I.e., the work groups and discussion groups and exchanging of ideas at initial RE&M phase happens amongst the government body (Armscor) the end user/client (SAAF) and the main contractor (BAE systems) only . And not with the subcontractor (Organisation A)
Respondent5	Main contractor is contractual baseline, ensuring that contractual baseline requirements that flow down from them are maintained and not unnecessarily changed and if it’s changed then a formal process is managed to change the requirements and I think on LIFT we were

	pretty successfully in doing that There is also to some extent a requirement on the main contractor in terms of the operational requirements, understanding what the actual requirement is from the end user and being able to properly convey and flow that down onto the subcontractor which we (Organisation A) were actually main contractor on the mission system at that point. So that's a responsibility from them, to flow down those requirements as well I think from the subcontractor's point of view it's also to be able to clearly derive requirements from the baseline, interpretation of the contractual requirements, to clearly define unambiguous set of requirements that we (Organisation A) use as our baseline Also involving requirements traceability, see how it's going to be managed From the government's role I didn't see too much of an impact on them on requirements as such except that in this case they were the end user at the end. So There is an issue there. But in terms of the general process I think there is some responsibility on government and government bodies in the military environment to ensure standards are in place and to support in the industry the whole principle of proper requirements flow down which am not sure was the case on LIFT
Respondent6	For the whole program, I mean, I cannot add much

	because I wasn't involved from the beginning of the program On OC4, the contract was an Armscor contract, contracted by the SAAF onto Armscor, which contracted BAE Systems, they were the main contractor of the HAWK Aircraft and they were also the design authority for the aircraft and they contracted Organisation A (subcontractor) for the supply of the avionics mission system; Navigation & Weapon System (NWS) We acted as the... Like I said the design authority of the Hawk was not given to us at the time but under BAE System guidance we signed off the avionics mission system.. Which I think guys have told you already and you are well aware of that. The requirements and specification requirements was flown from the Armscor to BAE systems down onto Organisation A... I see this in terms of the requirements... So ....In OC4 we had a requirements review, which I'm not sure it was always done in the others (OC1,OC2,OC3,OC4), I think it was there but I think it's part of the lessons learnt which we will maybe touch on later... but we did those requirements review on that We had a Requirements Verification Matrix (RVM). How we will test those requirements. Whether it would be by analysis or flight test, or integration bench testing etc. That is what the engineers did and yah, part of closure was to review these requirements and to see if we have met the

	requirements that have been placed on
Respondent7	In terms of contracting we have user requirements from the client which is now taken into the mission systems specifications and then that gets flown down into our specifications basically on the integrators level and we then have to make sure that the equipment suppliers we sub-contract, those equipment must then fulfil the requirements so we have to then flow down from the solution system integrator the requirements down to the component level So in some cases BAE systems has been the main contractor and obviously in terms of the government side, Armscor has played the role of contracting BAE systems and then Armscor take their user which is the South African Airforce (SAAF), their requirements into account and then flow it into BAE systems and then we respond to those requirements when it is flown down from BAE systems onto Organisation A Obviously in terms of the requirements engineering & management, it's a flow down initially and then part of the process is to verify the requirements. So there is a whole verification process where we take the verification evidence and feedback upstream so that at the end of the day Armscorneed to sign off each of those requirements as being compliant based on the evidence we supplied and we have the same interface with our subcontractors

Researcher Question3:	Requirements engineering & management at program management level
Respondent1	Get this information from a senior engineer or program manager
Respondent2	Speak to the program manager
Respondent3	Ask the program manager, I don't think I can really add value on this topic
Respondent4	I think in our process, program management delegate that task to the systems engineering level I also think that it is a mandate (in my opinion) from BAE that management don't get involved with technical issues and requirements engineering and management is a technical issue They (BAE) saw it was a conflict between safety and budgeting. If the systems and requirements engineering team state that '...we can't meet these requirements by this deadline...' that information shouldn't just be thrown away by management who are more interested in the deadline We've got that same set of roles now if you look at the organogram. We've got Bruce and Alan who sit as technical leads and then when there is that conflict between technical and budget then it gets resolved by someone independent, that is set up to resolve that same issue (Not to have a single person in management to in

	charge of technical issue) See Dirk's slides (Organisation A new structure organogram) that addresses this issue
Respondent5	The first thing was to ensure that proper reviews are performed specifically from the client or main contractor down to us (Organisation A) in terms of the interpretation, ensuring there is a full definition of the requirements at our level which forms our contractual baseline and that there is agreement between the buyer/main contractor (BAE) and the subcontractor (Organisation A) So you can go nowhere (and that is one of the lessons learnt, we'll get there) if you don't have a proper baseline to start with and the requirements are not completely and unambiguously defined then you have a problem Program management, one of the biggest issues is baseline management. To make sure you stick with and you freeze a baseline and you stick to that contractual baseline. Any changes to a baseline is normally a big issue downstream if its not managed properly. There always be changes to a baseline,(e.g. new requirements) preferably during development that shouldn't happen. The work should be done upfront and you freeze your baseline and you continue from there onwards. That's where you end up with milestone problems all of that if there is requirements creep and all of that Baseline Management: On previous programs, that was

	one of the major issues, I think on LIFT we were rather successful in managing that in the end. That you don't get because you always get from clients, no they just want this little bit added whatever and the impact is not always properly assessed and from systems engineering point of view there is always a tendency to 'yes let's do it, it's a nice to have, it will improve the system'. But in terms of the project and milestones and schedules, the impact thereof is not always assessed properly or understood when you agreed to that so when you want to do a baseline change it needs to go through a formal contract change and costing and everything needs to be assessed and scheduled/schedules
Respondent6	Well I didn't really manage that, I was more managing the schedule and the contractors and The requirements were all managed by Alan Geddes on the technical side. So for me it was merely to say that the RVM plan was done etc.. to measure the schedules that they were on time, the schedules that I managed and see whether we achieved our milestones and our goals that we set out to do
Respondent7	I think, if I understand the question correctly, in terms of, how does program management take requirements engineering and management into account I think our program managers, if we understand our process in terms of requirement flowing and traceability between high level specification and low level specifications... so they are fully aware of that so when

	they propose program schedules and program statement of works to do a specific project, they need to take this processes into account, so that all the requirements can be captured initially to have like that System Requirements review initially and then right through the process there is very specific points in which they need to plan for those tasks I think in terms of the technical review process that Organisation A has got, there's also in detail described all the different gates as you go from contract signature into requirements capture and then PDR, CDR and eventually qualification review. So all those steps, program management must take into account when they plan a program and all those associated tasks Technical Review Works Instruction – If you look at that you will see the whole flow and all the gates in terms of the review gates that we agreed we should use in our (Organisation A) process
Researcher Question4:	**Requirements engineering & management with suppliers and subcontractors**
Respondent1	When integration team got involved most of the suppliers and subcontractors had already been identified. The main thing here is to make sure that the product that contractors/subcontractors can supply. That that product fulfils all the requirements. To make sure of that with proper engineering reviews. So that all this is in place

Respondent2	I was not involved there. There the PCM database will give you some good examples of day to day requirements resolution issues
Respondent3	I know that at some stage there were jokes being made about Organisation A not managing their subcontractors. I wasn't directly involved in any subcontracting so I can't really say much about that. We were a subcontractor ourselves... Sorry I can't really say much
Respondent4	I don't think there was much management with requirements in between all..... The requirements are handed to a subcontractor who then tries to achieve them We hold our joint CCB (with our subcontractors) when we discuss issues around/surrounding those requirements And at that level I suppose what's an acceptable deviation from a requirement or how can we change it so that everyone is happy. I suppose is a level of management but it's actually very small and only surrounds the issues, which is normal
Respondent5	If you say with, I assume it is the interface with them and for me that's to ensure that there is proper flow down of requirements, firstly the requirements definition at the main contractor's level should be clearly identified and specified and then to allocate those requirements to the applicable subcontractors. Again it's on us, that task. And

	then to ensure that those requirements are properly flowed down to the subcontractors and contractors below you And to obviously manage the process thereof
Respondent6	At the time of OC4, it was done before the time. Again the requirements that was flown in the specifications that was put on us from BAE systems side for the aircraft, that is what we have flown down on our sub contractors as well. That was part of the contract. And also linked to the specification because in the beginning of the contract negotiations to my knowledge and I'm speaking in correction, that requirement was already put down...what can the system do? Can the system fulfil the requirements....that was initially for the Hawk contract... ? So it's flown down onto the subcontractors and suppliers. It goes on the technical and environmental. In some cases where we bought the was the so called off-the-shelf items, there was additional environmental requirements to fulfil the Hawk requirement, so we had to in addition contract the suppliers for additional qualification testing
Respondent7	I think its again, if you are placing a subcontract from Organisation A point of view to equipment suppliers, we have to upfront make sure that we flow down those requirements onto them. They need to provide us with a product specification and that product specification for

	each requirement in the product specification, they need to provide as part of that specification, a matrix in the back that defined/defines the verification method, that's initially and then later on as they start producing that, you need to now review that they have provided you with the verification evidence so some of it is ATP, some of it is maybe inspection or it can be different verification methods that the suppliers use to verify each of the requirements in the product spec, but they must as per part of their contract with you provide you with all that evidence From component suppliers, the main thing is on the ATP, they will have an acceptance test procedure, so they will cover most of their requirement from that, but then maybe some of the requirements they will need to use different methods to provide you with evidence
Researcher Question5:	**Interdepartmental requirements engineering & management coordination**
Respondent1	From integration point of view we have the product/ the LRU but we also have supporting tools which was developed in house. So yes to deal with interdepartmental business you also have to put your requirements out to them and make sure that they can deliver and they should know what you want even if it's just tools that you gonna use on the test bench. On the hardware there is always 2 levels. You get a specific hardware built/d and it goes through its stand alone ATP but as soon as you put it into

	the system usually there is some other influences that can cause that specific unit to fail. That is why the system level test is very important or that that unit should be tested in the environment that it is gonna be used
Respondent2	Here as well you can look at the PCM database. Any formal correspondence between Andrew and Alan would be documented in the PCM database and you can see which issues were raised between departments and you can get examples of what was done
Respondent3	That's where I think being part of integration comes in because as far as those requirements were concerned, integration was the subcontractor We were given requirements for testing Well if you consider Systems engineering to be a contractor defining the requirements and then software had to implement those requirements, so they were a subcontractor and then integration again was subcontracted to the level where we had to test it I think on the DFS level, the requirements were given through to software initially. Then they took over the management of the DFSs So then like in OC4, the requirements were given through a requirements definition document, I think you would remember those And then systems engineering and software engineering cooperated in defining the changes in the DFSs then it was implemented

Respondent4	We had a review process between departments. In OC4 we did the FDDR docs. We wrote requirements specifications that centred on each problem that was reviewed interdepartmentally and coordinated in terms of the efforts required and time scales So it was done via a review process I think there is probably a serious lack of interdepartmental coordination w.r.t the planning that's put on the table I think we will come to it just now on the lessons learnt It amounts to systems engineering telling software this is what you are going to do and this is when you will be done by Similarly to a contract comes down to us (systems engineering) and says this is what you going to do and that's when you will be done by. There isn't a consultation process There is no buy-in and we go down the chain
Respondent5	It's the same as point 4. You typically have interdepartmental divisions and the same principles should apply and the same principles should apply. Even though they are part of your organisation you should still ensure that the requirements are properly allocated and flowed down and there should be a formal baseline again same as there is one between us (Organisation A) and the main contractor (BAE), there should be a formal baseline of requirements flow down to software and/or hardware

	development or wherever, whether it is in your organisation or not
Respondent6	Again, I think the engineering people can comment better on that but errrr..engineers are responsible for FRS's which they wrote and usually they discussed with the software people to see if the software people could write the software to fulfil those requirements The systems engineers were involved with the software people during some of the testing (software testing)... I think you did some of that yourself. And the integration people later on was also involved in the testing... and they tested on the hand/end of the requirements And the ATP of course was written with view/from the specification to make sure that we do test that requirements and see if we fulfil that requirements
Respondent7	In terms of software we have the functional requirements specs (FRS's) which has got requirement traceability will lead to the higher level of specifications and then we expect the software guys to then take those requirements in the functional requirement spec. and to flow that down into their lower level software documentation, so that they have that in place In terms of the hardware side, on the hardware side they normally have a product specification, say a mission computer, so the hardware guys will have a product

	specification, and again in the back of the specification they will have a list of all the requirements to provide traceability up to the project. So I think they still implement it, although it's inside the company, there is definitely an agreed list of requirements that you measure the equipment against both on hardware and software
Researcher Question6:	**Use of Requirements engineering & management tools**
Respondent1	There is really a lack of tools in our environment. Many of these things were done manually. Requirements tracking from specifications to test procedures went through spread sheets and databases. It was done very manually. I think with a good tool it could have been much easier
Respondent2	So there is specific tools and there is a process. There is a specification. Mainly what needs to happen is compliance to the specification. So for the IFM because it provides one parameter the requirements was easy but the major issues were the environmental qualification. So we agreed with them what needs to be done there and they had to test it and provide evidence according to a qualification test plan provide a qualification test report. So that's the process used to prove requirements Management speak to Alan or John I suppose
Respondent3	It would have been nice if we had some and I think that in LIFT was the reason was so much work to be done as far

	as requirements management was concerned, Because it was all done by hand/manually with excel spreadsheets. So I believe it was done well but it took a lot of effort and time particularly on Alan's (Technical coordinator in charge of traceability) side. I mean to keep traceability was a nightmare without the correct tools
Respondent4	What tools? I think that's the whole answer We used excel spread sheets to map the process and to do a mixture of the time lines and technical requirements trace
Respondent5	complex, the systems that we develop. And I cannot see today's environment that you can do a development without having proper requirements management and traceability. I think that is something we learnt in the LIFT program, initially there was a bit reluctance perhaps and it was a new field for us, and we started that and by the end of the program everybody could see that there was no way we could have successfully done the program without actually going that route and getting the requirements in place and specifying all requirements and doing the traceability, Although it wasn't so straightforward in LIFT but I'll get to that just now You can have a smaller program and maybe not need to go and use formal tools or whatever but. Complex

	systems you must have tools We did in manually on life; I'll get to it just now... it becomes a huge burden as you go on
Respondent6	The MMI tool for me is a very nice example where we had a management interface tool, where we had.... and again it's not/there is no program management this, just manage it and make sure that the task happens... We had to/the review where had the pilots, we had systems engineers involved and where we reviewed the requirements on this tool and this we agree with this we agree ...with this.. the layout we agree with... Whatever symbol is correct, the colour is correct and all those things, that we have done on the function, as we implemented... interpret it the way that they understand it to happen, and we have changed, many times we have changed it, and we get minutes to be signed off, and we get the POD updated and signed off and that is then the baseline we work on. I think from management side, the only thing that we really want to drive to, is to make sure we have a requirements baseline that is agreed by the client with BAE Systems involvement and us of course involved and we have a baseline that we can work from
Respondent7	I think in Organisation A, we have done some management on manual ways of using, typically excel and variations of Work/Word, Macros and Functions, but that's

	not very successful. So I think recently we've started discussing DOORS and the use of DOORS, but so far due to licence costs it was not yet established in the company. So I think it's something that in the future we will go towards, using DOORS on any of the new programs to actually use DOORS as the source of all the requirements and from there actually generate the specifications. I think my feeling is that so far because of a lack of tools, it's been quite limiting in the way that we use requirements. Initially we capture them, and then maintaining the requirements if there is any changes later on becomes very difficult if you don't have proper tools to manage them
Researcher Question7:	**Requirements engineering & management problems experienced [biggest mistakes]**
Respondent1	Sometimes out of an engineering requirement, you've got your requirements but then you sometimes are led by what is available and you sacrifice maybe some of your requirements and you say this LRU/equipment is qualified it is available or is the easier route and then you say ok, we'll go with that and I think in the very early early phases maybe more time can be spent to source the ultimate solutions maybe. Solutions vs. Time lines and time scales
Respondent2	Just in general I think the problems experienced in Requirements engineering is people inexperience. People don't understand the impact in a requirement. Ambiguity in

	a requirements – people read a requirement which is ambiguous and they don't request that requirement to be clarified and when it comes to requirements qualification it's impossible to prove that requirement because it is ambiguous So there's probably look at it and come up with other problems experienced
Respondent3	Well I think one of the biggest problems was not having a proper requirements management tool. That led to things being missed and a lot of additional work. And then I dare say I think the actual management of the requirements testing came a bit late in the program. That is something that should have been done from the start like it is now with black label program (with the doors tool as you write your requirement, you also complete the test method) I mean we were years down the line doing integration testing before we even looked at what the requirements were. What the requirement numbers that were allocated were. Then we only started working on the traceability in the integration test procedures. It was more or less when you (Interviewer) started working at Organisation A (ITPs and ATPs) when we started populating requirement numbers in the test procedures and seeing if there were any requirements that weren't tested So basically we built the bench and tested the bench and then only went back to see if the bench fulfilled all these

	requirements. Yes, but that was already far into the program. That was 4 or 5 years into the program I think that was one of the biggest mistake, trying to play catch-up rather than doing it from the start
Respondent4	I would say the biggest mistake we had in the LIFT program from the beginning was a underestimation of the effort involved in/with traceability Towards the end/In the end we had a process that we developed in order to cater for it however it was extremely manual and required a hell of a lot of effort which would not have been the case had some form of tool been used to do this in the first place been However I personally still hold some reservations as to whether a tool will solve the problem or if it's just going to move the work from the front to the back, back to the front People see for instance DOORSas a complete solution to the traceability problem, which it may well be. How much effort is it going to be to get DOORSup and running properly versus how much effort is it to do traceability manually as it is being done now? I'm not sure that the time saved is going to be so massive. I think we are going to make a whole lot of new mistakes due to the tools So I have no doubt that 5 projects down the line, using

	tools is definitely a better solution. I think that the tools for the next project may well be a worse solution We gonna take a step backward before you take a few steps forward
Respondent5	I think for me and it's not LIFT specifically, it's in general. Is that establishment of a sound baseline that supports lower level structures. If you don't define your high level requirements according to certain rules and a nice structure that supports breaking down the requirements in lower levels for instance if you have duplication of requirements and sometimes they are ambiguous (specifies different issues but it is basically the same requirement) Requirements that doesn't really fit in perhaps or Is the clients dream where you start implementing design and not requirements... So the way you break down your higher level requirements which forms your contractual baseline. That should promote or support this whole process. Otherwise you end up with a lot of difficulties. You can still end up with a list of requirements and you can for each requirement provide evidence that you've met the requirement but you actually start missing the point the requirements and after verification the whole validation process. After you've validated your set of requirements you should

	be able to say ok, the system is ready to go its what the client wants Automation vs, Manual. One of the mistakes we tried the automatic process and tools in the beginning and we didn't really get that going so we ended up with a manual process and in the end we've been able to manage it but it became quite a huge burden, every time you need to freeze a baseline to ensure that all requirements are ~~ready~~, correctly pressed and all of that and all the paperwork are synchronised and so that was quite one of the lessons learnt Rather start with a good tool even if it costs money upfront and ensure that you use that tool correctly because it will help you downstream Proper traceability Something we managed to be able to do to some extent on LIFT. I think at lower levels there was proper traceability for the software because they had to do it for certification but wasn't always so easy to get traceability from the high level right down to ....and that's because of our manual process If you have a correct tool like where we are going now with DOORS. And you do that correctly, you can trace a requirement right down to the lowest level and it's definitely a requirement to be able to do that Especially if you start doing changes to a system and if you don't have traceability in place and you change a part

	of the system; to go and identify exactly what's the impact and you don't have traceability.. There is a lot of risk that you involve there because you might not be able to define the whole impact and it changes and it impacts places where you don't expect it to change and all of that so... you need proper traceability to support managing changes to a system
Respondent6	Again you know maybe its interpretation/expectation, I think in the beginning there was some requirements that was maybe a bit ambiguous, maybe not tied down nicely as we would have... this is what we want to do... and then the client had maybe a different idea and says but he thinks it happens..to. the requirement slightly different.. We've had differences on what.. the interpretation of the requirement... So that's what I think is/as problems Of course we experienced some problems during the testing.. You implement something and test it and see it's not working as nicely as we implemented or from the integration bench you fly it dynamically, its not what you expect it to be, the aircraft behaviour plays a role in it These are the normally things that comes into play there
Respondent7	I think up to recently, it's been under estimated, the importance of requirements traceability, and how much that actually helps you in the later phases of the program. And then of course the not having proper tools to do requirements tracing and management, it's been also seen, your tools can actually cause you to then eventually

	start doing everything in manual mode, and it becomes quite difficult to... because all the higher level specifications if you change something it starts flowing down then you start doing manual updates on those requirements at lower and lower levels which then becomes very time consuming
Researcher Question8:	**Requirements engineering & management positives [success stories]**
Respondent1	Skilled people and in this specific case the character of our whole team was skilful and we had a committed team. We kept a good control on the whole project. At any certain stage we knew what was outstanding where we were and where we were going. Even if there's a lot of open issues we knew what it was
Respondent2	Communication – We had good communication in LIFT, which assisted in requirements resolution. We met with the end user, so we could discuss requirements and remove ambiguities so that was a positive. Strong program management – on LIFT where the program is actively managed. People know what they are doing. There is a schedule there is a plan, you know what your deliverables are and when they are due so strong program management is a positive from there
Respondent3	I think we managed to overcome the shortfalls and the penalties so to speak

	We had this penalty of not having DOORS, so we had to do everything by hand and still we overcame that obstacle and we managed to get design approval on Hawk, that is a sign that BAE systems has confidence in our ability to manage requirements
Respondent4	Learning from our mistakes and going forward each iteration worked better in my opinion So If you look at the process in 0C4, going into it, we had a much clearer and defined plan and methodology of how we would do each piece exactly because we'd gone through it those 3 times (OC1, OC2 & OC3) That's my concern with using the tools is we going to throw the baby out of the bath water and start a fresh... This is a new way of doing it
Respondent5	On LIFT we did it with a manual process but in the end it was a key mechanism to be able validated the system in the end and identify where there is non-conformances to the specifications and all that and where we have evidence and where we still need more evidence .... If you do a requirement, a requirement alone and the characteristics if you don't have the test procedure and the mechanisms you going to test that requirement or validate that requirement then the requirement means nothing. So you need a full scope of requirements and understand how you going to provide evidence and follow that whole V principle. So if you don't start of and have proper requirements specified, the testing is going to be lacking

	and you cannot make sound decisions on how you going to test it. So you end up testing a function but it dies in the end So I think that was a success story on LIFT, that we actually have been able to manage requirements capture even though it was manual and it was a huge process to go through, to every time go through the whole loop and go and see where we've managed to provide new evidence and where not and where there is new non-conformances wherever .. it was the only way to do it
Respondent6	I think in OC4 when we came to it, it's not to say we didn't do it properly the first time, but with the more experience the guys had, we did requirements review, that was an important factor.. Which I think we can spend more time on is to make sure that the requirements review.as with this MMI tool we used . is that we have a good understanding and the client sits around a table with us and says..is this what you mean, is this how we understand it... is it clear... What is the requirement? How we will test to meet that requirement? And that agreement is agreed upfront before we start going to the contract base I think that's where we have improved a lot on... that for me would fall into a positive outcome on this
Respondent7	I think what we've seen is that if you have requirements traceability in place, to make modifications on a baseline,

	if you carefully manage the requirements that have changed and you can then look at justifying what verifications need to be repeated, you are in a position to motivate it, you don't have to re-test everything, so you can just do partial testing, and it becomes easier to justify that all the test evidence is still applicable if you have requirements traceability in place...so that's been helpfully On the software side, we've spent a lot of time, if you make a software change, what does it actually affect in different areas in.... basically to identify what re-testing needs to be required if you make a change. So that's typically to define a regression testing based on the change you've made I think there's positive spin-offs from requirements engineering there, and then also positive thing is to incrementally build up the maturity of the system, you can actually by looking at the requirements, and which requirements have been verified, you can measure your system maturity by looking at all the requirements you can then start measuring and seeing how you system mature towards the end, where initially you see say the first 70% of the requirements you cover quickly, and then you start seeing it slowing down, and then you see the last 20% or 10% takes a lot longer to get that but I think it is something you can measure the maturity of the system in terms of verification evidence

Researcher Question9:	**Requirements engineering & management lessons learnt and what can be done to improve the process**
Respondent1	In the early days the systems engineering and integration worked apart. If we could have worked together at that stage and even took the requirements then and to start formulating the tests. What happened is that systems engineering did their work and then it flowed down to integration engineering/team and the integration team would start to write their tests per requirement. At the end the integration team struggled to get all the requirements tested. But if we worked parallel from the start, we could have had more success
Respondent2	See the lessons learnt database
Respondent3	I think it ties in with other questions The biggest lessons learnt is traceability must be managed right from the start. Playing catch-up on that is a hard/difficult thing to do
Respondent4	Lessons learnt database, I didn't think much came from it. A lot of the comments are very utopian, in a perfect world it would work as follows. If I take a very good comment you (Faith) made where's the training? It is totally viable but there are budget constraints and that's reality. What can be done to improve the process? In my opinion 100% is to negotiate to a level that is a negotiation over time scales and not something handed down from the top

	that says you shall meet this Some people may say that we had negotiations previously, but I think that is a smokescreen I think that the probably one of the outcomes of this type or research that you are doing is to go into the hands of the contractor/government/armscor to say that someone who takes what your 'contracting request' and says yes they can achieve it without some sort of negotiation or discussion is probably not a decent solution and that you could get a lot better/you could be a lot better off at the end of the day with a lot more consultation
Respondent5	I think on new programs what we are trying to do is to right upfront agree on a structured process to do requirements and get agreements straight out of the table and discuss how we going to do this and get everybody's input and have a consolidated view on how you going to address all this whole requirements through different levels, what requirements are going to look like, have reviews on them and then go on to the next step and discuss how we going to do the traceability Spend enough time upfront to ensure that you have a sound process don't try to do it later and again we sit in programs where because of time scales whatever, you are already down the process sometime and now you need to in retrospect go and fix all of that The longer you wait the more difficult it becomes and then

	you're sort of stuck in a process that is not ideal So yes spend enough time upfront Have discussions, I think most of engineers know what a requirement looks like and what it should look like .. This comes to the planning part as well... But there should be some. Everybody has their own idea how they define requirements and at least try and get some consistency between various people working on the same program Agreed on how traceability will be managed at different levels, know which documents are applicable at what level and have a nice picture, we've actually done that yesterday on Black label... To go and say ok this is our baseline, there is a contract to requirements, this is our baseline what we going to put in there, what documents going to be underneath there upto the FRS's and the hardware specs and have a clear view on how we are going to do the traceability. And we actually went in circles quite a few times before we got agreement so it's not a straightforward task; you need to spend time on it
Respondent6	We can improve on the review, the requirements review, that we must improve, to understand a bit better The DOORS tool, that we have started to implement, that is for me a very positive outcome And the way we write our documentation.. The flow down

	from the current documentation to DOORs was not always an easy task we used...was done on the excel spreadsheet and then we, our documentation did not clearly ....we can go maybe go back to some of the mistakes we made/had ...is to leave your requirements and when you write the specifications and the POD for example, the way you write your requirements must be so set up that your, set up nicely in DOORS, you can flow down from there, that makes it easier to meet the requirement ...it's a difficult task and to get it agreed between what we have in documentation and what we was the contract.. you go to the excel spread sheet that was drawn by Alan and he had to do that, and was fed into DOORS by BAE systems... And that agreement...and there was not so clear on the requirement and what was the end...what we had measured... what we meant... and what they asked So that is I think, improved already, implementing now, and in the future must be used to, have a proper requirement tool that we can flow down and measure it
Respondent7	I think we, first of all looking at generating of requirements, our specifications when we generate requirements we need to spend a bit of time on generating better requirements in terms of the best practice in system engineering where you have very clear requirements, that's accurate, that's got verification methods defined as well with the requirement,, so that if you start tracing it down, that you don't struggle later on because it wasn't

	not a real good requirement initially, so I think the quality of the requirements is very important and then you need proper tooling that you can then start managing it downwards So I think the specification, and a lot of times specifications you write certain things in that's not necessarily requirements and I think you need to specifically identify it like that. That certain areas of the specification, you're not going to trace down, but then be specific as to here the requirement start and you have an identifier for each of the requirements and then you start tracing. Because in specifications, you can have like background information.. all sorts stuff that you need in the specification to have a good specification, but you need to clearly say ok this is now the actual requirements that you start tracing, so...
Researcher Question10:	**Requirements engineering & management training? Should engineers attend such courses? Discuss?**
Respondent1	I think in a whole engineering team there is gonna be one or two guys with a lot of experience that went through a cycle already. But there's gonna be few guys that haven't done it before and I think that if that guys can be trained and make sure that they know where to go or if that leader of that group is very strong. He can be lead them There needs to be a balance between training and experience and exposure

Respondent2	I agree there should be, if there are courses that can add value people should go on those courses definitely
Respondent3	I never had such training until Ad Sparrius courses- Acquisition management, Systems Engineering These training are very critical/important especially when one is a systems engineer and has to write requirements related documents and specifications Systems engineering is all about requirements, writing requirements, deriving requirements, managing requirements, designing a system to fulfil requirements
Respondent4	I have no idea My personal view points are very far from other people I don't believe I got any value out of any of the training we got given. Other people found it very valuable, So I'll just decline to comment on that
Respondent5	Am not so sure that we should place too much emphasis on the whole course issue, I think it's good to do courses and whatever but in the end it is not an actively involved thing, you sit there and listen to somebody The first thing for me is, if you want to do requirements engineering and management, the first thing is that the engineer should start of by knowing what is a requirement and how to define a requirement Yes there was training done on that and it is a logical process to some extent as well

	The second thing for me is to have internal discussions and work sessions and agree and because there is a level of experience and your environment is a lot of times different to other environments which might not apply to training there is, they tend to provide an overall sort of picture in the training but the way to get to a final answer is what works for you in your environment and that comes with experience; Sitting around a table and actually discussing and get peoples input and get into an agreement. The whole requirements, the management and traceability and all of that its not a difficult subject, it's a matter of.., it's like configuration management, you can discuss that and everybody has their own views and you can in 2 months time on the same/whole project have the same discussion again and everybody has their own views, but in this case it is not a difficult issue, you need to apply your experience and sit around a table and upfront discuss how you going to do this and have a plan and get agreement on that I can assure you when you get to the next project, you are going to do it differently, because some stuff maybe didn't work whatever and training cannot give that path/part for you So I am not too concerned about the training aspect Anybody with the level of experience that we have in this type of environment, whatever, should know what it is and

	what it should looks like and should have a clear idea....getting consensus Faith: My experience with training is that I learnt and finally understood the Systems engineering There is a lot of value in the training and especially for new people. There is certain concepts that you need to know in order to be able to apply it. But I think a lot that came with experience as well. And as I said it's like.... if you have a new concept and you don't understand it, normally it's rather an easy thing. But until you went through the process of understanding it then you look back and say... ok but this is actually a bit easy. If you don't understand the concept you need training or whatever or somebody to give you guidance to understand the concept. But once you understand it you can start applying it
Respondent6	From a program managers point of view That is something we have to do, you know I don't have much experience with a tool, again it goes to how we write requirements, some of the the tools we need to use, there is some improvement to be done...its not just how we write the requirement, is how do you write, because you must write it in a certain way, to get it into DOORS and to flow down properly, so we can gain a bit more experience on that, I think, there is always way to expand on it

Respondent7	Yah, I think especially in terms of generating specifications, errm, and then also using tools if there is specific tools. So engineers must be sensitized as to how to write proper specifications and proper requirements and then to apply the tools throughout the company. So that training can be for example external, the Ad Sparrius type of courses and then also on the internal processes of Organisation A, for example, the Technical Review Works Instruction, those type of Organisation A process that's already established, training should be done in such a way that everyone, is aware that there is such a process defined in Organisation A and that they should actually follow it.
Researcher Question11:	**Are project completion delays, missed milestones, dissatisfied customers and increased costs attributed to poor Requirements engineering & management?**
Respondent1	I think in our specific case with a project manager that is technically strong all these can be managed. There can be delays and missed milestones but it can be managed as to what causes the delays, maybe you it's not necessary to take all the blame because there outside factors that causes this and if it can be managed and can be visible then yah.There are also external factors that affect these things and not just requirements. Usually we need answers from the main contractor and if there is a delay in that answer there would be a delay in deliveries. I

	think all these should just be managed
Respondent2	Yes It has a big impact on those points you have underlined. If you look at it now. Our main contractor is very dissatisfied because our requirements Definitely project delays are influenced by Requirements Engineering & Management That's half of the course (in Andrews opinion) If you had perfectly specified requirements and perfect program management, then you would always be on time and you wouldn't miss any milestones and your customer would be satisfied. But the real world is full ambiguities and acts of God, people get sick, requirements are badly specified and they get through the system, time constraints, resource planning – are there enough people to do the job, maybe the requirements are bad because there are not enough skilled people to do the job. Current project, the user requirements we received from the supplier were ambiguous, they expected us to write concise requirements, there wasn't enough time so at the PDR, the client was dissatisfied because there was still ambiguity in the requirements. The original requirements weren't dissimilated to usable requirements Maybe look at development of requirements. You don't just arrive at requirements You get a URS but you probably got all that information. Thats normal Ad Sparrius. Then you review the requirements, you take away ambiguities and you review your definition of requirements to the customer. He signs

	up to those requirements so when you have stable requirements... All the role players agree with those requirements and that's something that is not achieved many/all our programs Then it comes down to program management. Does the program manager have the teeth to get the requirements to be sorted out. There might be a contracting model that's poorly put together that allows for bad requirements to go through. So there is lots of factors that can influence bad requirements Monetary, time scales, I think every company wants money to come in so they probably will want sign anything as long as they can realise/get cash inflow for their projects So you get a company that is down on its order book, might quote for business unrealistically and because of that resources are scarce and therefore your requirements dissemination is not up to scratch and therefore you get poor requirements and therefore later down the line of the program you have dissatisfied customers, missed milestones, completion delays
Respondent3	Well I've seen first-hand what dissatisfied customers are like. When it comes to deriving requirements maybe not fully understanding what the requirements are. You get requirements and you implement those requirements in/to

	your understanding. And in the end when you get to the flight test phase, the flight test pilot is unhappy the work that is done because the requirements were either poorly interpreted or not fully understood and they were implemented in a way other than what the customer expected And we actually made changes in 0C4, by involving the flight crew early in the process making changes showing it to the customer/flight crew getting the customer's/flight crew's feedback Feedback/Communication is key! Get the customer's feedback earlier in the process rather than going through a full development in the software, getting into a test phase and only then finding out afterwards that the customer isn't happy with what you've implemented So communication with the customer is actually very important
Respondent4	Very very little. Because project completion delays. I think we completed on time every time almost Missed milestones were made Customer was satisfied What I think it contributes towards is people working overtime, stress levels in a company and then deferred issues So the milestone is made with an agreement that it this should have been in at, wasn't in at and will get in for free in the next one It's a technical answer; it's a political answer to some

	degree but I wouldn't say requirements engineering and management has any impact on project completion delays, missed milestones, dissatisfied customers in our instance And I also think that we did the RE&M very well which is why we got yes, yes and yes if I say to those three we didn't mess it up **Are** these things (project completion delays, missed milestones, dissatisfied customers and increased costs) attributed to poor requirements engineering and management: I don't think we had poor requirements engineering and management
Respondent5	It boils down to the same thing, If you start off with ambiguous and incomplete requirements, misinterpretation of those requirements, a lot of times when you end up with a client whatever, it's not what they expected because maybe on their side the requirements wasn't properly defined and on our side there is more than one way to interpret their requirement So I think the mitigation for that is to again when you have the contractual requirement and this requirements have flowed down to yourselves and you've done the break down; it becomes you baseline, to have a proper review, not just err..., you must sit there and get agreement on that and spend time to make sure those requirements are properly broken down ok and that's the subcontractors

	responsibility and not the prime-contractors responsibility So the firstly there is two levels on that, have a review on that and at least start off with a baseline that you agree on, there will still be misinterpretation or different ways of interpreting. The way to get around that is to have them involved early on during development and actually see what it looks like. I think that's one of our primary goals with the COD and the fact that we have reviews on the COD, to mitigate the risk of them not being happy with the final product. But even if you start implementing it and have the system running, get the involved as soon as possible But normally that can lead to quite a bit missed milestones and delays. But is something that can be managed. If it is not managed, it's going to end up leading to big problems
Respondent6	I think that's a.... to measure may not be clear but it's important to, if you're not happy with it then you will incur costs, We have to re-test, we interpret it this way, we implement it somewhere and the test came, the client said am not happy with this, so we had to re-write the software, we had to re-test, repeat the flight tests... that was fairly huge cost incurred by that Milestones yes can be missed, because of what you think you delivered is correct and the client says I'm not happy with that its not correct so we had to go back and fix it so So how much to measure it that is difficult but we had

	slipped and we had incurred additional costs... I think that’s a fact
Respondent7	Yah, it is difficult to generalise, I think it does play a role, for me on the one side, you need to get the requirements engineering and management in place and then make sure that you have all the necessary reviews with the client included as well at the necessary stages in the program, so that your client can continuously influence your perception of a requirement. A lot of cases where we have dissatisfied customers is where we have expectations gaps, where from an engineering point of view, you understand that they want x, but actually that they want something else, so with requirement engineering management, you also need to improve your communication with the customer and the end user in such a way that you can make sure that whatever you deliver will satisfy them.. And obviously schedules and missed milestones can be a problem, especially if you underestimate a task, by not understanding fully what is required of the deliverable So the answer is that it does play a big role in completion delays and missed milestones and dissatisfied customers
Project2:	**Unmanned Aerial Vehicle (UAV) Vulture**
Researcher Question1:	**Your function/role in this project**
Respondent1	Mission Systems Manager- Responsible for all the

	functional aspects of the program across all platforms System Engineer –
Respondent2	Program Manager
Researcher Question2	**For this project, discuss main contractor's role, government's role or sub contractor's role w.r.t Requirements engineering & management**
Respondent1	Client – Armscor End User – SANDF (Artillery division) Main Contractor – Organisation A The product was developed for the government. Client was Armscor Armscor is the armament procurement agency in South Africa. They are responsible for contracting industry for all projects to meet all the requirements of the South African Nation Defence Force (SANDF) including the Airforce, Army and Navy South African Army namely the Artillery division had a requirement for an Artillery Targeting Engagement System (ATES). The system was a very big project called project Klooster. It consisted of a number of systems that would support target engagement with the South-African artillery Primarily it comprised of 3 areas of sensors Short range sensor - An infantry man/foot soldier would use a laser range finder mounted on a tripod to geo-locate

	a target and then to transmit the coordinates to a flight control centre and the flight control centre would find the target, measure the position of the target and determine the correction and then transmit the correction back and then the whole battery would fire (BAOS) Night Time and Daytime sensor- which is on a truck which had a huge arm/y and got deployed and covered a range up to 10km UAOS- Was the Aircraft, carried the range from 10km to 60km which was the aircraft which flew around and did the same thing Armscor sent out Request for Proposals (RFPs) to industry based on the requirements. Industry came up with proposals based on the requirements. Organisation A participated in the proposal for the UAOS which is the aircraft side of the ATES The User provided a basic set of requirements, industry responded with a proposal and then from the User Requirements Specification (URS) those requirements were analysed and we/ Organisation A put together a system level requirements specification And that System Level Requirements Specification became the basis of contracting Requirements engineering and management was done manually. No specific tools were used. Traceability was

	achieved on a manual basis. A system requirements document was compiled and then a systems specification was compiled A cross reference table in the systems spec. which cross referenced all the requirements in the system spec. to the URS In each sub system, there was a sub-system requirement. Those sub-system requirements were cross referenced to system requirements via a compliance matrix
Respondent2	Management Role (Armscor) Main contractor – Armscor (government organisation) They are the purchaser. They put the contract on Organisation A for the vulture project. They have to approve all the changes on the program. They handle all the financial matters and progress on the program. They also have to get approval from the end user (SANDF) in terms of approval of certain deliveries regarding the usage of the system in the user environment So they interface to the end user (SANDF) The end user was the SANDF/SA Army Engineering Role (Armscor) They evaluate in conjunction with the end user the compliance to any engineering requirements that we (Organisation A) fulfilled

Researcher Question3:	Requirements engineering & management at program management level
Respondent1	We (Organisation A) had a concept definition phase, where based on the requirements we did the systems engineering analysis to break the requirements down to sub-sections / sub-systems that would satisfy the various requirements. For example in vulture we needed an aircraft to fulfil the requirements. User requirements were broken down to a global system and then to sub-systems. Various functions were allocated to sub-systems The main purpose of the launcher was to launch the aircraft and the secondary was to carry various other equipment e.g. cameras, nets, tools and equipment that the soldiers/people that operate the system need to use to perform their functions etc GCC – needed to monitor the aircraft while in flight and at the same time pass the information between the UAOS and the rest of the ATES system. All the Command Control and Intelligence (C^2I) functionalities
Respondent2	Program manager was responsible for the technical performance of system, as well as the financial control as well as the schedule in terms of the deliverables. Engineering team performed the technical work and reported to the program manager with regard to the engineering progress

Researcher Question4:	**Requirements engineering & management with suppliers and subcontractors**
Respondent1	Based on a systems engineering process, you establish a list of high level requirements which the launcher/GCC is supposed to achieve and then you go through the process of designing a system We went through the process of designing the system quite closely with our subcontractors. There were not many off the shelf products that we could just go out there select see what satisfied our requirements and then select, we actually had to develop plenty of the equipment. Majority of the equipment was developed We established all the requirements for all the sub-systems, we sent out these requirements to subcontractors. Essentially you sent out a Request For Quotation (RFQ) and RFP and you include a whole list of requirements and the contractors come back with responses to these in terms of meeting each requirement. It is a process of negotiation We were in a position to decide whether non-compliance was acceptable or not because we were given the authority (by the contractor-Armscor) to do so. When we did accept a non-compliance we were required to motivate it

	Our Client was happy that we did all that engineering Often we have a high level contracted requirement which we are forced by contract obliged to meet and some of that stuff is ridiculous/really stupid.. Not a lot of lateral flexibility
Respondent2	Contract is placed on subcontractors for specific items to be supplied at the management level and this includes engineering requirements or technical requirements of this. And normally the engineering team liaise with the subcontractors to see if they comply with our (Organisation A) specifications/requirements
Researcher Question5:	**Interdepartmental requirements engineering & management coordination**
Respondent1	We relied a lot on simulation. We simulated most of our functions before we wrote out the DFS's Detailed Functional Specifications (DFS) were written in enough detail such that the software engineers to implement straight Systems engineers would simulate and with the aid of simulations they would write out the DFS's In general Flight Control Systems, Navigations Systems functionality generally sit on other boxes/subcontractor equipment, however with the vulture all these sat on the

	main computer box/mission computer They are very process intensive, lots of calculations and computations. so most of the time we simulated everything From simulations we wrote out DFS's. DFS's are detailed enough for software guys to implement straight Software engineers/developers would then write SRS's out of the DFS's i.e. copy and paste from the DFS's into SRS In terms of requirements engineering & management, all requirements are transferred to the software team via a DFS Software were required to meet all these requirements from the DFS and they had a traceability in their SRS's back to our DFS's DFS was FRS but was more detailed than the FRS DFS would encompass FRS and SRS functionality Software generated the design documentation i.e. Software Design Description (SDD) and data dictionaries Systems engineers/Integration engineers wrote the acceptance test procedures (ATPs) and cross referenced the ATP's back to the DFS's

	For everybox that was developed by the hardware department or an external contractor, we (UAV systems engineers) produced an Interface Definition Document (IDD) e.g. IDDs for the IMU; MSU; AVAC; PMU;PCU A subcontractor developed the Data Link and we had a requirements specification written out for that. This was a separate development that happened in parallel LCP and LCB Subcontractor managed the LCB however there was and ICD between the LCP and LCD and we managed the interfaces between the two.
Respondent2	As program manager, I normally interacted with the rest of Organisation A and management level for the support of the other departments but the lower level engineering contact is then contacted by the engineering team
Researcher Question6:	**Use of Requirements engineering & management tools**
Respondent1	Requirements engineering and management was done manually. No specific tools were used. Traceability was achieved on a manual basis. A system requirements document was compiled and then a systems specification was compiled A cross reference table in the systems spec. which cross referenced all the requirements in the system spec. to the

	URS In each sub system, there was a sub-system requirement. Those sub-system requirements were cross referenced to system requirements via a compliance matrix
Respondent2	We normally used in-house type tools to do all our engineering stuff for that and we didn't have any company wide common tools to help us in this process
Researcher Question7:	**Requirements engineering & management problems experienced [biggest mistakes]**
Respondent1	Not enough time allocated to systems engineering activities at the beginning of the program before establishing the functional baseline and allocated baseline The biggest mistake is that the PDR is scheduled far too soon in the process. Most of the time they want to do it because they want to realise cash flow because PDR is usually a huge milestone and that usually attracts a lot of income. The consequence is the design evolves a lot more after the PDR which is not supposed ~~to happen~~.
Respondent2	Tools – Lack of Requirements Management Tools
Researcher Question8:	**Requirements engineering & management positives [success stories]**
Respondent1	Close interaction between system engineers and Software engineers - The team was small and system engineers did

	the initial integration to a large extend and worked very closely with the software engineers. Close interaction between system engineers and software engineers was a huge success Continuity- Requirements traceability was done manually. The only reason that was successful was because there was continuity; the key systems engineers (Grant and Arno) were involved for the whole project/through the whole project. They remembered everything and could relate/answer questions/solve problems throughout all phases of the project For a big program if there was no continuity, managing requirements/requirements traceability would have been a huge failure. The same/key group of engineers started the project and ended the project. That was a big success. Conversely if that hadn't happened it would have been a huge failure This is mainly consequence of unformalised/manual requirements traceability
Respondent2	Experience of the team engineers/technicians, and all those involved in the project

Researcher Question9:	**Requirements engineering & management lessons learnt and what can be done to improve the process**
Respondent1	Requirements traceability from the start is key! At the end of the project the client required/Grant was required to produce a document which determined what the test coverage for the system was from a functional point of view Because of a lack requirements traceability, some tasks/activities given to newer engineers took unusually long because there was a lack of requirements traceability throughout the project It was a huge effort to get the requirements traceability in place after the time. To cross reference all the tests that had been done to all the requirements, even after delivery of the final version of software, that process identified errors that were not adequately tested
Respondent2	Less development of all the components used in the system. Rather do more integration of off-the-shelf items. Buy off the shelf items and then slightly modify and adapt especially on the airframe side... because design and manufacture of UAV airframes is a huge task and a huge component of costing
Researcher Question10:	**Requirements engineering & management training? Should engineers attend such courses? Discuss?**

Respondent1	Basic Systems engineering and system management courses to get the idea and processes in place should be taught. The rest should be learnt through application Implement good practice, procure tools that are identified that essential/good to use and then just use them. Engineers learn through application
Respondent2	Set time for training of engineers with regard to the systems engineering process There is not enough time set out to get people trained in areas where they could improve the process to save time scales because we are always pressured in terms of time
Researcher Question11:	**Are project completion delays, missed milestones, dissatisfied customers and increased costs attributed to poor Requirements engineering & management?**
Respondent1	Missed milestones - as a result of scheduling design reviews (e,g PDR) too soon in the SE process within the project. This usually results in income/financial penalties Proper baselining of the product being developed. It is very important to baseline and then only proceed from there. Don't proceed from there until all TBDs are resolved A good method/idea is to throw everyone's/every system engineers effort toward closing the TBDs. We cannot continue until this is done. Allocate all resources to solving the TBDs and then everyone continues. Rather than having other people continue down the line and it

	becomes difficult to manage Dissatisfied customers - New requirements that came in later on in the process, resulted in delays with the main contractor (Organisation A) and also subcontractor this led to a dissatisfied and disgruntled customer. This also led to delays that naturally lead to increase in costs.
Respondent2	There wasn't a huge extent on any of the project deadlines or milestones, it's probably the fact that additional products needed to be delivered in other areas that delayed some our initial deliveries... due to the requirements and the quantities changing in the process It's probably not engineering and management it is the change of the scope of the work in the process introduced delays