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MASTER

The development of a maintenance concept for the Multi-purpose Airborne Radar System

Breebaart, Andrea

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The development of a maintenance concept for the Multi-purpose Airborne Radar System.

Student:	Andrea Breebaart
Id.nr.:	402604
1st Supervisor TUE:	Prof. dr. P.C. Sander
2d Supervisor TUD:	Ir. R. J. van Baaren
Reviewer TUE:	Prof. dr. ir. A.C. Brombacher
1st Supervisor Fokker Space RAMS:	Ir. W. Kruidhof
2d Supervisor Fokker Space RAMS:	Ir. R.A. Bosman
Supervisor Fokker Space MARS:	Ir. P. Snoeij

Eindhoven University of Technology
Faculty of Technology Management
Department of Industrial Engineering

Leiden, December 1999

Acknowledgements

This report describes the graduation project performed by Andrea Breebaart at Fokker Space. The last 8 months I have been engaged in the field of reliability and maintainability for a remote sensing system. The result for Fokker Space is a Reliability, Availability, Maintainability and Safety assessment of the PHARUS and MARS radar systems and a maintenance concept for the MARS system.

I learned a lot from this graduation project. What I liked the most was to learn many new things in a completely new area. To work mainly with engineers was very encouraging and also challenging. Therefore I would like to thank all the people from Fokker Space, who took the time to help me and who provided me with the specific technical knowledge that I needed to finish my graduation project. Besides Fokker, I want to thank all the people from TNO, KIM, Holland Signaal and MEOB, who contributed to my graduation project.

This graduation project was very challenging because I worked in the corporate environment of Fokker Space, where high tech products are developed. Microwave remote sensing systems were a new technology for me when I started my graduation project. This implied that I encountered new problems every day and therefore I learned a lot.

Furthermore I would like to thank my supervisors. At first I would like to thank all the supervisors from Fokker Space, because they assigned me four supervisors. Matthé Keulemans, Reinier Bosman and Wim Kruidhof helped me with the RAMS part of the research. Furthermore, I would like to thank Paul Snoeij a lot, who was the supervisor from the MARS project and together with Frank-Martin Seifert, they knew everything about remote sensing and radar systems.

From the TUE, I would like to thank Peter Sander, for all the entertaining hours we spent on discussing my graduation project. He was a very dedicated supervisor, and visited Fokker Space every month. From the TU Delft, I would like to thank Ron van Baaren, who was willing to be my second supervisor for my graduation project and who guided me very effectively with the development of the maintenance concept.

At last, of course I would like to thank my family and all my friends for the interest and support they showed regarding my graduation project.

Andrea Breebaart
Leiden, December 1999

Abstract

This report presents the development of the maintenance concept for the flight segment of the MARS system. To develop the maintenance concept, the system was first analysed in the field of reliability, availability, maintainability and safety. These analyses had the purpose to evaluate the system and at the same time the analyses made clear on what the maintenance concept should concentrate. Almost simultaneously the maintenance concept was developed.

Summary

This report describes the graduation project performed by Andrea Breebaart from the Technical University of Eindhoven. The objective of the research is the development of a maintenance concept for the flight segment of the MARS system.

MARS project

MARS is a remote sensing radar system for earth observation, which is developed by Fokker Space for BPPT in Indonesia. The main objective of the MARS system is forest monitoring in Indonesia. The technology used for the MARS radar is derived from an existing technology used in PHARUS. MARS is basically a copy of the experimental PHARUS system. MARS and PHARUS are basically the same systems.

BPPT, the Indonesian Agency for the Assessment and Application of Technology, is a governmental technology institute and is a comparable company to TNO in the Netherlands. BPPT wants to learn from this MARS system. Indonesia will then be able to implement the planned upgrades into the MARS system and in the future even develop similar systems themselves. So it is a so-called learning project, which makes it different from a normal project. This learning project also implies that BPPT should be involved in the re-engineering of MARS. Re-engineering implies that the components, which are not available anymore, because of ageing, will be replaced by equivalent components. During the development of the MARS system, the tropical environment and corporate cultural circumstances of Indonesia must be taken in account. The design of PHARUS will not be changed for the MARS system.

MARS system description

MARS is an airborne imaging radar and exists of two parts, namely:

- Flight segment, where the flight data is recorded, collected and stored. The flight segment includes the following subsystems: the radar system housed in a pod and mounted under an aircraft, a data acquisition- and data storage system inside the aircraft and a data conversion system on the campaign base;
- Ground segment, where the flight data is processed and converted into digital images. The ground segment consists of a parallel PC network.

Motive for Research

The MARS system is currently re-engineered because it is a copy of the experimental PHARUS system, which is currently used in Holland since 1995. MARS will not be an experimental system like PHARUS, but a system for operational use.

MARS is an operational system and will be used in Indonesia for forest monitoring. The RAMS analysis has to make clear what the performance, quality and problems of PHARUS are. PHARUS is an experimental system and just some field data and failures are registered. They did not develop a maintenance concept for PHARUS. A maintenance concept is necessary for the operational MARS system, which will be used in Indonesia.

Assignment

As a result of the above paragraph an assignment is formed and consists of two parts namely:

1. Do a "Reliability, Availability, Maintainability and Safety" analysis of the MARS and PHARUS flight segment.

2. Develop a maintenance concept for the MARS flight segment, which will be used in Indonesia.

The assignment for this graduation project consists of an analysis phase and a design phase, which have been gradually executed.

Realisation of research

In the beginning a plan of action has been set up to accomplish the assignment. The plan of action covers the analysis and the design phase of this graduation project. Before the analyses could be done a mission profile has been set up to determine requirements for the MARS system.

The MARS project is a result of a mutual co-operation of Indonesia, represented by the governmental agency BPPT, and the Netherlands, represented by the Ministry of Economic Affairs. Indonesia must use a radar system because they are obliged by an international regulation, to do forest monitoring with the application of a remote sensing system.

BPPT did not set strict requirements for the MARS system. So for this research a mission profile has been set up. This mission profile describes the most likely scenario of the application of the MARS system. This mission profile determines the starting point for the requirements for the RAMS analyses and the maintenance concept.

In the analysis phase, the PHARUS system has been analysed in the field of reliability, availability, maintainability and safety. The most effective RAMS analysis methods for this research were selected from all the possible RAMS analysis methods, as described at the Fokker Space RAMS website. The RAMS analysis had the purpose to evaluate the system and at the same time the analysis made clear where the maintenance concept should focus on. The analyses did not have the purpose to change the PHARUS design.

The design phase of this graduation project includes the development of the maintenance concept. This maintenance concept is developed for the end user, BPPT in Indonesia. The RAMS analysis forms the foundation for the development of the maintenance concept. The analysis identifies the critical items for maintenance.

Resources of information

For this research also other information resources apart from Fokker Space are used. Interviews with people from, TNO-FEL, Holland Signaal, TU Delft, KIM and MEOB were held to get more information about RAMS and RADAR systems.

Reference books also made a contribution to the research. A theoretical scope illustrates the results of the literature research and contains the following subjects:

- Reliability engineering;
- Development of a maintenance concept;

- Different characteristics of the MARS radar system and the working of RADAR.

Furthermore a description of the MARS system is given to make clear what the MARS system includes, how the MARS system is built up, and what the characteristics of the MARS system are.

RAMS analysis

The RAMS analysis is executed to evaluate the PHARUS system and to find out what the critical items of PHARUS are. A reliability analysis is done to make a reliability prediction of the PHARUS system. The reliability of the PHARUS radar is 0.79 for the total operating time, 3300 hours.

For this research the following analyses were used:

- Functional Block Diagram;
- Reliability Block Diagram;
- Reliability Prediction;
- Availability analysis;
- Maintenance analysis;
- Failure Modes Effects and Criticality Analysis;
- Maintenance identification;
- Safety analysis;
- Hazard analysis.

The analysis contributed to the maintenance concept, which is developed. Especially the FMECA is a frequently used analysis to develop a maintenance concept. The FMECA identifies all possible failures and furthermore identifies what the consequences of the failures are within the system or on the environment and identifies what the maintenance critical failures of MARS are.

Maintenance concept

The development of a maintenance concept was the assignment for this graduation project. The development of the maintenance concept could not be completed. To develop a maintenance concept with the most time- and cost effective maintenance rules, information about costs of units and repair time of units must be available.

The maintenance concept that is developed is divided in the required preventive and corrective maintenance. Furthermore it is described what support is needed regarding when, how, who, what and where maintenance must be done.

The maintenance concept will be delivered together with the MARS system. The maintenance concept will be used in Indonesia by BPPT. MARS is also a learning project for BPPT, which means that Indonesia wants to learn and master the microwave remote sensing technology. If BPPT does most of the maintenance themselves then they will learn the most from the high frequency technology and the practical implementation. A maintenance concept will describe how the causes of the failures can be identified and what equipment is necessary for the diagnosis and the repair of the failed units.

What is developed as the maintenance concept for the MARS flight segment, for this graduation project, is described in chapter 8.

Conclusion

The conclusions of this research are divided in the following five parts: reliability, maintenance, safety, MARS project and availability. In the following paragraph, short summaries of the conclusions of these five parts are given. More detailed conclusions and accompanying recommendations are described in chapter 9.

Reliability

A reliability prediction of the radar system is made with the aid of a partscount according to the military standard of electronic system. The reliability of the other subsystems is allocated according to the ratio between the reliability of the radar system and the complexity factor of the radar system. With this ratio, the reliability of the other subsystems can be allocated. This allocated reliability can be used as a requirement for the purchasing of the subsystems.

The MARS system includes a lot of Single Point Failures. But the radar system fails with a probability =0.00036 per flight (5 hours), which implies that 1 out of 2778 flights fail because of the failing of the radar. According to this calculation and comparison with the required availability, no extra reliability measures for the MARS system have to be taken to achieve better reliability.

Maintenance

The maintenance concept could not be completed because not all the required data was available. To develop a maintenance concept, data and information about costs and repair times of the subsystems and units must be available. Otherwise it is not possible to determine what the most time- and cost effective maintenance rule is for a unit.

Safety

The MARS system does not have a lot of human machine interfaces. So safety is not very critical for MARS. Some situations can be critical, which are the movement and transportation of the pod of 250 kg and the radiation of the T/R modules can be harmful to people. These aspects must be looked after, with the use of MARS in Indonesia.

MARS project

The subcontractors for MARS must detail the maintenance concept more thoroughly. The subcontractors must deliver maintenance guidelines for the units or subsystems they provide. These guidelines must describe how and when the maintenance actions must be initiated in Indonesia. A good tuning about required training, skills, tool and equipment between Fokker Space and BPPT is necessary to finish this project successfully.

This graduation project started in May 1999. At that time the MARS contract with Indonesia was supposed to be signed already. Now the MARS project is postponed for an indefinitely time because of the political instability of Indonesia. The consequence of the delay is that costs of re-engineering will keep increasing.

Availability

Availability is not a driver for this system because the flight segment will be used 16.5 % of the time. Time to repair is available, and the system is maintainable, so a failure of the system is accepted.

Table of contents

1 Introduction to report

This report describes the final graduation project executed within Fokker Space in Leiden. This chapter serves as a general introduction to the report. This research is done for the MARS system. The MARS system will be often shortened to MARS in the report. The abbreviations and definitions used are included on page 55 and 57.

This chapter will show how this report is built up and what the relations between the different chapters are. The following figure gives a schematic overview, which illustrates the relations between the different chapters of this graduation report. Every chapter starts with a short introduction to the chapter and ends with a short conclusion. This conclusion summarises the objective of the chapter and the relation with the following chapter.

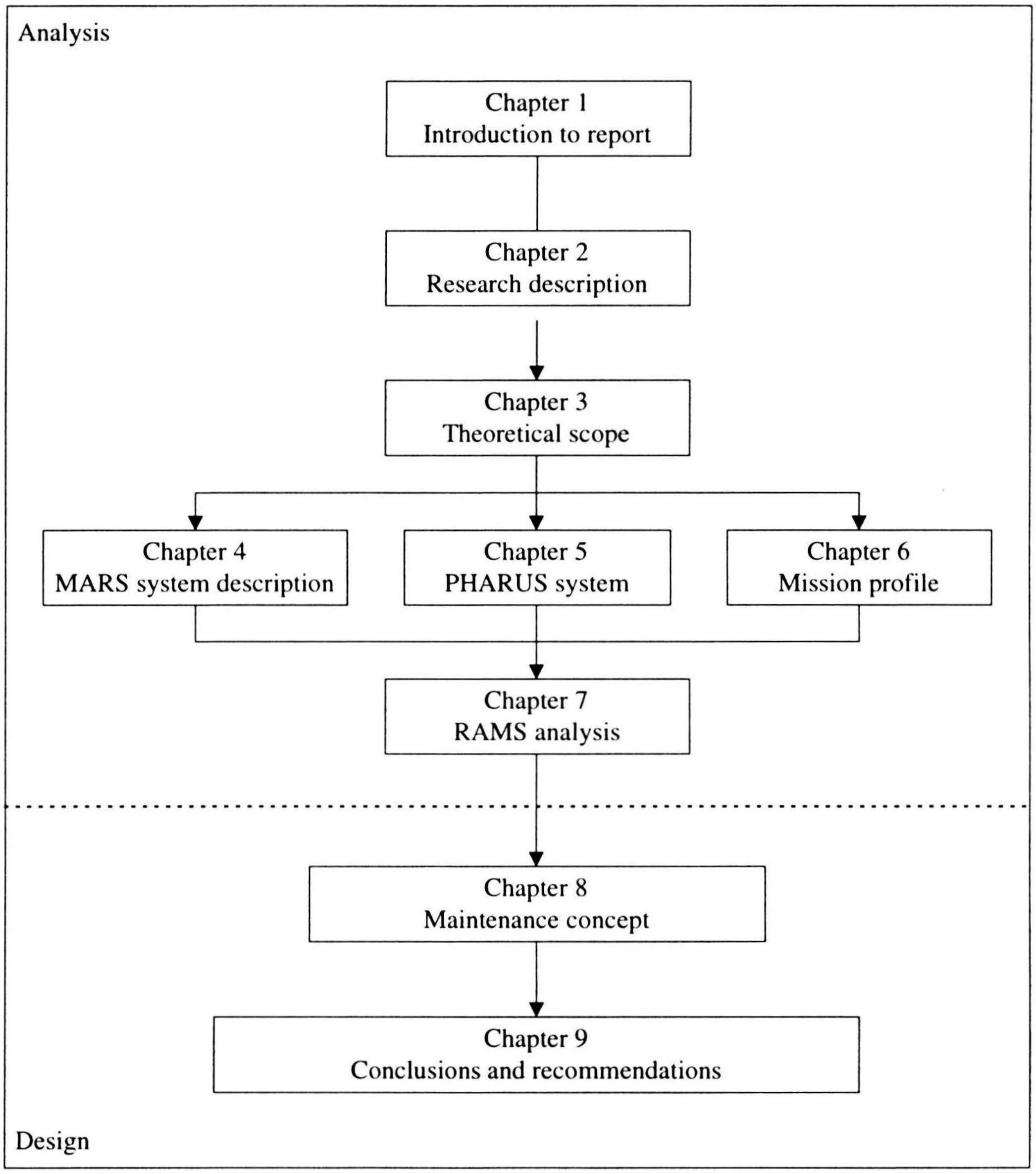


Figure 1.1 overview of the arrangement of chapters

1.1 Chapter descriptions

The second chapter serves as a research description. First, a short description of the company Fokker Space is given. The second paragraph gives a short description of the origin and purpose of the MARS project. Furthermore the motive for the research is described and what the problems of the research are. The objective of the research is to develop a maintenance concept for the flight segment of the MARS system on unit level. Why the research does not cover the whole MARS system is described in the research demarcation. In the following paragraph the plan of action is given. In the plan of action it is described how the research has been executed. In the last paragraph the information resources, which are used for this research are described.

In the third chapter a theoretical scope is given. The objective of this theoretical scope is to compare the theory of certain topics derived from literature to this practical research. For this theoretical scope a few aspects are discussed, which are the following: reliability engineering; RAMS of electronic systems, development of a maintenance concept and the different characteristics of the MARS radar. These three aspects are looked at and put in relation to the MARS system.

The fourth chapter gives a description of the MARS system and the MARS project. At first, the resources, which will be made available by BPPT, are given. The functional description and the block diagram of MARS are given to illustrate the MARS system. The physical and environmental characteristics are described to show under what circumstances the MARS system can be used. Finally, the future upgrades, which are planned, are described.

In the fifth chapter the PHARUS system is described to show how MARS and PHARUS differ. So first the system and user differences are given. Then the way PHARUS was used is described. Furthermore the failures that occurred in PHARUS are described.

In the sixth chapter the mission profile of MARS is described. Because the end-user did not strictly set the system requirements, a most likely scenario for the application of MARS is determined. Furthermore the operational plan is described and the operational time has been estimated. The operational plan, the operational timeline and the most likely scenario together form the mission profile. The mission profile gives the input for the RAMS analysis.

The seventh chapter describes the RAMS analysis. The RAMS analysis consists of different analyses focused on reliability, availability, maintainability and safety The RAMS analysis are done to evaluate the PHARUS system. The RAMS analysis supplies a good foundation for the maintenance concept.

The eighth chapter describes the maintenance concept. First it is described how a maintenance concept must be developed. In the second paragraph an introduction to the maintenance concept is given. Then the corrective maintenance and the preventive maintenance for the MARS flight segment are described. Furthermore is described what support is needed for the maintenance. The last paragraph describes what the maintenance cost for MARS include.

The report is finished with a chapter of conclusions and recommendations. In this chapter, 20 conclusions and accompanying recommendations are set forward. The conclusions are derived from the analyses and the observations made during the research period. The conclusions are divided in five parts, namely: reliability, maintenance, safety, MARS project and availability.

2 Research description

This chapter describes how the research description came about. In the first paragraph a short description of the company Fokker Space is included. The second paragraph gives a short description of the origin and purpose of the MARS project and also what the meaning of this project is for Indonesia. The third paragraph describes what the motive for this research is. As a result of the research motive the problem description is given. In the fourth paragraph the objective of this research is described. Why the research does not cover the whole MARS system is described in the research demarcation. In order to do the research, a plan of action is made and described in paragraph seven. This plan of action describes how the research should be realised. The last paragraph describes what resources of information next to Fokker Space have contributed to this research.

2.1 Fokker Space

Fokker Space is the number-one Dutch player in the international space industry, with over 480 employees. Based in Leiden and with roots in the renowned Fokker group, Fokker Space became a fully independent company in 1995. Fokker Space was established in 1968 as space division within Fokker.

Over the past thirty years it has been a participant in major domestic (Dutch), European and other multi-national space projects. Among the fields covered are solar arrays, launchers, robotics, simulation, payloads & remote sensing, small systems and thermal products. Applications are found in telecoms, earth observation, astronomy, (space) transport and defence.

Remote sensing is one of the product groups of Fokker Space. The unique expertise areas of the remote sensing group are ozone monitoring, coastal zone management and forest management. Measurement techniques use Imaging Spectroscopy as well as Synthetic Aperture Radar (SAR). The projects can be grouped as:

- Instruments for earth observation;
- Software tools for remote sensing;
- End-to-End systems for remote sensing.

Together with partners, Fokker Space develops operational End-to-End systems that include sensors, ground-based data processing, education and training. The ultimate aim here is to provide users with an optimum, cost-effective service. Therefore, the users are closely involved from the start. A recent initiative is the MARS project for forest management.

2.2 MARS project

The MARS (Multi-purpose Airborne Radar System) project is a result of a mutual co-operation of Indonesia, represented by the government agency BPPT, (Bandan Pengkajian dan Penerapan Teknologi) and the Netherlands, represented by the Ministry of Economic Affairs, who has given the industrial co-ordination in the hands of the private company Fokker Space B.V.. BPPT will be the buyer of the MARS system. BPPT is a governmental technology institute. The MARS system will be delivered within two and a half years after the contract has been signed with BPPT. A deliverable besides the MARS system is the maintenance concept for the MARS system. This maintenance concept will be used in Indonesia.

BPPT, the Indonesian Agency for the Assessment and Application of Technology, is a company comparable to TNO in the Netherlands. In 1999 the Kyoto confederation has declared that Indonesia, and all countries with tropical rain forests, are obliged to start forest monitoring. More information about forest monitoring is available in appendix D.1. The Kyoto confederation is an international confederation that monitors the emission of CO_2. Furthermore they regulate and monitor the forestry. Indonesia is legally obliged to monitor 30 million-hectare, every 5 years. 10 million hectares can be done with optical or aerial photography. 20 million hectares must be done with the aid of remote sensing. The number of hectares will increase in the coming years. Therefore Indonesia wants to acquire and master the high frequency knowledge, which is required to develop and make microwave remote sensing systems, like MARS.

As a result of this, the MARS project is at the same time a study (learning) project for BPPT. BPPT has the purpose of learning the high frequency technology from this MARS system, so Indonesia will be able to implement the upgrades of the MARS system themselves and also develop similar remote sensing systems in the future themselves. Also with regard to maintenance this implies that they will want to do the maintenance themselves as far as possible. In this way, BPPT will learn the most from the MARS system.

2.3 Motive for research

The MARS is a remote sensing system for earth observation. The objective of remote sensing is to map areas of land or sea in a short time. The MARS system is currently in the re-engineering phase (see appendix A.1).

The MARS project will be derived from an existing technology developed in the PHased ARray Universal Synthetic aperture radar (PHARUS) instrument. PHARUS is an experimental system and has been developed in a co-operation between the TNO Physics and Electronics Laboratory (TNO-FEL), The National Aerospace Laboratory (NLR) and the Delft University of Technology (TUD). The PHARUS instrument has been developed over the past 7 years and is flying experimental and pre-operational campaigns since 1995. MARS will not be an experimental system like PHARUS, but a system for operational use. MARS will be an exact copy of PHARUS as far as possible. Some components will not be available anymore, because of ageing, so equivalent components will replace these parts. The replacement of components within the different units implies re-engineering and not a design change of the PHARUS design.

Re-engineering is defined as to make the necessary adjustments to components or systems so the component or system fits again in the functional design. For MARS re-engineering implies the adjustments that have to be made to let PHARUS work under tropical conditions. Furthermore re-engineering for MARS requires the replacement of components that are not available anymore, by equivalent components.

For the MARS flight assembly so far only one design change is made, which is the following: In the data storage system the tapes will be replaced by harddisks because the tapes will stick together because of the humidity in Indonesian.

2.4 Problem description

As a result of the motive for the research, the following problems came up:

1. MARS will be an operational system and will be used in Indonesia for forest monitoring. The MARS design is based on PHARUS, which is an experimental system. Therefore, a RAMS analysis evaluates the system and makes clear what the performance, quality and problems of PHARUS are. Furthermore the RAMS analysis makes clear what the maintenance critical items are;

2. A maintenance concept for MARS should be developed, which will be delivered with the MARS system to Indonesia.

The description of this research consists of two parts and is formulated as follows:

Within the scope of the MARS project, investigate in the Reliability, Availability, Maintainability and Safety (RAMS) aspects on unit level. Use these RAMS aspects to develop a maintenance concept for the end-user.

2.5 Research objective

As a result of the defined research description the objective of the research is defined as follows:

Develop a maintenance concept for the MARS system on unit level.

2.6 Demarcation

The maintenance concept will be developed for the flight segment of the MARS. The ground segment is not part of the research because the ground segment is still in an early re-engineering phase. Furthermore the ground segment exists merely of software which runs on parallel computers. So this research will be restricted to the flight segment of MARS.

2.7 Plan of action

The plan of action is set up to create a way to execute the research. The research consists of two parts, an analysis phase and a design phase. Before the analyses can be done a mission profile is set up to determine the requirements of the MARS system. This plan is one way to come to a maintenance concept. In the next paragraph is described what the mission profile, the analysis phase and the design phase include.

Mission profile

The objectives of MARS and the customer requirements of the MARS project constitute the mission profile. The objective is forest monitoring in Indonesia. The customer usually defines requirements. The requirements set by BPPT are not complete. Therefore a mission profile is described in chapter 6 and is based on a most likely scenario and expectations of the application of MARS.

Analysis phase

This research consists of an analysis phase and a design phase At first the PHARUS system will be analysed in the field of reliability, availability, maintainability and safety (RAMS). These RAMS analyses had the purpose to evaluate the system and at the same time the analyses made clear on what the maintenance concept should concentrate. The RAMS analysis is the foundation for the maintenance concept. After the analysis a maintenance concept can be set up. The analyses will be quantitative as well as qualitative. The RAMS analysis for MARS consists of the following analyses:

- Functional Block Diagram (FBD);
- Reliability Block Diagram (RBD);
- Reliability Prediction;
- Availability analysis;
- Maintenance analysis;
- Failure Modes Effects and Criticality Analyses (FMECA);
- Maintenance identification;
- Safety analysis;
- Hazard analysis.

These analyses are a selection out of the many different analyses, which can be used for RAMS. The first selection is made out of list of 43 RAMS methods, derived from the RAMS website of the Fokker Space intranet [26], and is given in appendix A.2. A second selection of analyses from this list is made, which forms the above list. I made this selection in consultation of my RAMS supervisors of Fokker Space.

The RAMS analysis and the conclusions of the RAMS analysis are described in chapter 7. The outputs of the analyses are included in appendix E. For the execution of the RAMS analyses, the reliability programs of the Reliability Analysis Centre (RAC) [13] and the Fokker Space RAMS handbook [1] are used.

<u>Design phase</u>

For the MARS project a maintenance concept will be set up. The RAMS analysis is the foundation for the development of a preventive- and corrective maintenance concept. The definition and the contents of a maintenance concept are given in chapter 8.

2.8 Resources of information

For this research several information resources, beside Fokker Space, are consulted and used. The purpose and results of these information resources are described below.

Fokker Space is a company who makes merely space products. Most of the space products do not require maintenance because it is simply not possible to do maintenance in space. The MARS radar is one of the few airborne systems, which Fokker Space develops and requires maintenance when it is needed. Fokker Space does not have a lot of information about maintainability and MARS is the first RADAR they develop, therefore it was useful to look at comparable systems from other companies.

First Prof. Ir. van Genderen was approached who is a professor in the field of RADAR technology at the Delft University of Technology, and also works for Holland Signaal. He was approached to see if he had information about comparable systems within Holland Signaal or TUD. Holland Signaal is a Dutch company, that is specialised in designing and producing of integrated defence systems for command & control, sensor and communications purposes. RADAR systems, in all sorts of applications, like satellites, airborne and ships, are also one of the products that Holland Signaal develops and manufactures.

Prof. Ir. van Genderen referred to L. Cornelissen who is a reliability specialist within Holland Signaal. He worked at the APAR (Active Phased Array Radar) in the field of RAMS. Mr. Cornelissen gave a lot of information how reliability is used in practical environments, like

APAR. Furthermore he provided the Blueprints for Product Reliability from the Reliability Analysis Center (RAC) [13].

Also drs. F.J.M. Raaijmakers, lecturer in reliability at the KIM (Royal Institute of the Marine), was interviewed and ir. P. Calbo, head of maintenance department of SEWACO (SEnsor Weapon and COmmand) was interviewed about the maintenance of their RADAR systems. Mr. Calbo showed me around the SEWACO Company and showed me what a maintenance concept for military systems included.

In November 1999, I made a visit to the MEOB, (Marine Electronic en Optical Company). The MEOB is a division of the navy, and they have different maintenance facilities for their radar systems. The visit had the purpose to verify the results of the development of the maintenance concept. It furthermore served as a comparative research for my graduation project about how the MEOB initiates the maintenance actions of their radar systems. I interviewed people from the engineering department, and was shown around in the laboratories and the radar facilities.

Of course TNO was consulted and asked for information of the PHARUS system. Several visits contributed to the development of the maintenance concept.

The course "*Introduction to maintenance and maintenance control*" from the Eindhoven University of Technology also contributed to the research. This course supplied basic knowledge in the field of maintenance.

Literature was consulted during the research project to verify observations and findings and to complete my research, see the literature list on page 53. A theoretical scope was a result of these reference books and is described in chapter 3, theoretical scope.

2.9 Conclusion

This chapter indicates why this research has been done, what the problems are and what the plan of action is to do this research. The objective of this research is to develop a maintenance concept for the flight segment of MARS. Furthermore it is shown, which information resources, beside Fokker Space are used and what their contribution to this research is. The next chapter describes what the theoretical scope for this research includes.

3 Theoretical scope

In this chapter a theoretical scope is given for the research project. The theoretical scope is divided into three parts. The first part includes reliability engineering and other RAMS aspects in relation to electronic systems. The second part concentrates on how a maintenance concept can be developed and what the maintenance costs include. The last part discusses RADAR and gives an explanation of the different RADAR characteristics used in MARS.

3.1 Reliability engineering

MARS exists mainly out of electronic systems. Only the pod, mounting points and cooling system are mechanical systems. So the reliability of the electronic systems is the most important. In appendix B.1, an image of the PHARUS pod is included to illustrate the pod mounted under the aircraft. Inside the pod, the electronic system is housed, the inside is visualised with an image, which is included in appendix B.2.

The definition of reliability is the following:

Reliability is the probability that an item can perform its intended function for a specified interval under stated conditions [10].

3.1.1 Electronic system reliability

Electronic components characteristically have a constant failure rate in the operational period. Therefore, repairable electronic systems usually show a decreasing failure rate trend, due to the fact that as defective components fail and are replaced the proportion of defectives in the population is reduced. The typical 'electronic' failure mechanism is a wear-out or stress induced failure of a defective item. In this context, 'good' components do not fail [10].

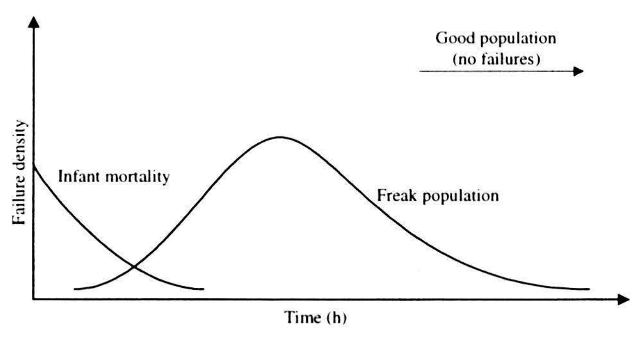


Figure 3.1 Typical failure density functions of electronic components

Figure 3.1 shows the three categories of components that can be manufactured in a typical process. Most are 'good', and are produced to specification. These should not fail during the life of the equipment. Some are initially defective and fail when first tested (infant mortality), and are removed. They therefore do not cause equipment failures. However a portion might be defective, a workmanship error or material defect, but nevertheless pass the tests. The defects will be potential causes of failure at some future time. Typical defects of this type are weak wire bond connections, silicon, oxidation and conductor imperfections, impurities, inclusions, and non-hermetic packages. These components are called freaks [10].

The most commonly used standard database of failure rates for electronic components is MIL-HDBK-217, Reliability prediction of electronic equipment [14]. The handbook gives failure rates for all types of electronic components, taking into account factors that are likely to affect reliability. MIL-HDBK-217 assumes independent, identically exponentially distributed times to failures for all components.

3.1.2 Maintainability, maintenance and availability

Most systems are maintained, i.e. they are repaired when they fail, and work is performed to keep them operating. The ease with which repairs and other maintenance work can be carried out determines a system's maintainability. Maintained systems may be subject to corrective and/or preventive maintenance. Corrective maintenance includes all actions to return a system from a failed to an operating. The amount of corrective maintenance is therefore determined by reliability. Corrective maintenance can be quantified as the Mean Time To Repair (MTTR). Assumed is that the time to repair of a unit or a system does not systematically change in time.

The time to repair includes several activities, usually divided into three groups:

1. Preparation time: finding the person for the job, travel, obtaining tools and test equipment, etc.

2. Active maintenance time: actually doing the job.

3. Delay time (logistics time): waiting for spares.

Preventive maintenance seeks to retain the system in an operational state by preventing failures from occurring. This can be servicing, such as cleaning and lubrication, or by inspection to find and rectify incipient failures, e.g. by crack detection or calibration. Electronic systems should only be subjected to calibration or hard time periodic tests as preventive maintenance. The objective of hard time tests is to detect the hidden failures in the system. Drifts in parameters or other failures can cause the system to operate outside specification without the user being aware, calibrating the system can get the units back to specifications. Mechanical systems subjected to wear, corrosion, fatigue etc. should be considered for preventive maintenance.

Maintainability affects availability directly. The time taken to repair failures and to carry out routine preventive maintenance removes the system from the available state.

3.1.3 FMECA

The primary consideration of all maintenance decisions is neither the failure nor the frequency of occurrence of the failure, but rather the consequences of that failure upon the system and environment. So each unit of the system should be analysed from the possible failure to the consequences of the failure. The most frequently used engineering tool for performing this task is a Failure Modes Effects and Criticality Analysis, FMECA. The FMECA of MARS is included in appendix E.2.2.

The purpose of a FMECA is to identify all possible failure modes with their related causes and effects on the performance, its external interfaces and safety. Also the criticality of the failure is to be assessed and solutions must be proposed to reduce or control the criticality.

Different FMECA's like, process-, functional-, human factor-, hardware-, and software FMECA can be distinguished. The FMECA for the MARS project concentrates on maintenance and is merely a functional FMECA. The application of the FMECA for this research is further described in paragraph 7.3.1.1.

Results of the FMECA can divide the consequences of failure into two groups, namely: the failures that have either safety consequences or utility consequences.

3.2 Development of a maintenance concept

In this paragraph it is described how a maintenance concept can be developed. First it is described what the definition of a maintenance concept is and includes and furthermore it is described how a maintenance concept can be developed.

3.2.1 What is a maintenance concept?

A maintenance concept is defined as the collection of rules regarding when, how, by whom, and with which means, maintenance must be performed on the technical system. [21]

When: When should the scheduled and preventive maintenance take place in order to prevent the system from failing. And when and where should the corrective maintenance take place.

How: How should the units be repaired and or replaced; set up the execution rules as far as necessary. The execution rules describe what the maintenance actions should include in order to get the system back to the state of availability.

Who: What education or knowledge should a person have to be able to repair or replace the unit.

What: (With which means) What equipment, tools and spare parts, are needed in Indonesia to detect, isolate, locate and repair failures in units and to replace units.

For MARS, a maintenance concept will be delivered. This concept is developed during the re-engineering phase of MARS. During the operational phase of MARS, the concept should be revised and adjusted to the operational application and failing of MARS.

Three kinds of maintenance policies can be distinguished to initiate maintenance actions namely [20]:

Corrective maintenance:
1. Failure based maintenance policy, which implies the initiation of maintenance actions after a critical failure;

Preventive maintenance:
2. User based maintenance policy, which implies the initiation of maintenance actions as a quantity of time);

3. Condition based maintenance policy, which implies inspection or examination of system, and dependent of the result of check, a maintenance action is initiated).

These three kinds of maintenance actions cover the different maintenance rules, which can be prescribed. In appendix F.2 it is prescribed how to decide what the most effective method of doing maintenance is for the different units of the MARS system.

3.2.2 Development of a maintenance concept

For the development of a maintenance concept different methods are available. Some of the methods are described below, for more elaborate descriptions read [12]. The different methods can be used separately or in a combination. Furthermore some methods cover the same aspects. Most methods use a FMECA, as analysis tool.

Reliability Centered maintenance (RCM) [17]
Reliability Centered maintenance was developed in the aviation industry to determine scheduled maintenance policies for civil aircraft. It has since been adapted for the manufacturing and process industries.

Maintenance Steering Group (MSG)
MSG was first known as a handbook on maintenance evaluation. MSG described a method for designing preventive maintenance programmes for aircraft. It was used initially to develop the scheduled maintenance programme for the Boeing 747. The method was very successful and MSG-3 has now become the established process for developing maintenance programmes for aircraft worldwide.

Integrated Logistics Support and Logistic Support Analysis (ILS/LSA)
Integrated Logistics Support and Logistic Support Analysis are methods which are developed by the Department of defence, (USA). The method is directed towards the provision of all necessary resources for the maintenance of the system.

Kelly [16]
Kelly aims to determine the best way of maintaining individual items, and secondly to determine the most appropriate combination of individual maintenance tasks for the whole system, to achieve the most economic use of labour and maximum system availability.

Gits [20]
Gits has developed a similar method like Kelly. But another characteristic of this method is the quantitative determination of failure effects.

For the development of the maintenance concept for the MARS system the above methods are looked at, but not a specific method has been used. The FMECA supplied the foundation for the maintenance concept and a maintenance identification completed the maintenance concept.

3.2.3 Maintenance aspects

No method from the above methods is chosen, for the development of a maintenance concept for MARS. Because no information as costs and repair times are available. PHARUS is an experimental and unique product, so I looked at the different methods and literature about maintenance to find out what elements are important for a maintenance for MARS.

This paragraph describes what maintenance aspects should be taken in account when a maintenance concept is developed. Not all of these aspects are important for MARS, so I made a selection for the important issues. I selected the aspects from the literature I have read about maintenance. The maintenance aspects are given below:

- Safety: What can happen when maintenance is performed (e.g. radiation, weight of pod)?
- Reliability: Does the reliability change after the maintenance action?
- Required resources: What is needed to do maintenance as far as tools and equipment?
- Training: What training is needed?
- Scheduled maintenance: When should the preventive maintenance take place?
- Corrective maintenance guidelines: How must the corrective maintenance be executed?
- Costs: What are the involved costs of the maintenance action?
- Critical units: Special attention is needed.
- Non-critical units: No special attention is needed.

Questions that also should be taken in account, but are less important for MARS are the following:

- Availability, how does maintenance effect the availability?
- Life cycle costs, what are the costs of the system?
- Qualitative decline, does the system degrade because of maintenance?
- Downtime, what and when is the downtime?

The following aspects are BPPT responsibility:

- Labour, who will do the maintenance?
- Tools and equipment that are needed should be acquired by BPPT and can be advised by Fokker Space.

3.2.4 Costs of maintenance

The development and use of a system involves costs during the different phases from the development until the end of life of a system. All costs, which are associated with the life cycle of a system, are called the Life-Cycle Cost (LCC) and involve cost of the following phases [23]:

1. Research and development

2. Production and construction cost

3. Operation and maintenance cost

4. System retirement and phase-out cost

In appendix B.3 a cost breakdown structure is included to show what the total system cost involve during the different phases (life cycle) of a system [23]. One part of the total system costs involves maintenance costs.

When a maintenance concept is developed, an important aspect to make decisions is costs. Depending on how important the system and the availability of the system is, a decision in costs will be made. Systems that have to be available 100%, will have a preventive maintenance program to keep the system from failing. Because the costs or effects of a failing system will be higher then the costs of preventive maintenance actions. Costs together with availability determine whether preventive- or corrective maintenance actions are more effective. For every system an optimum between costs and maintenance must be found.

The costs of maintenance of a system are dependent from [21]:

- Costs of system standstill because of failure;
- Costs of production standstill;
- Costs of labour, equipment and material.

In paragraph 8.6 is described what the maintenance costs for MARS imply.

3.3 RADAR, RAdio Detection And Ranging

Radar's are widely used and have all sorts of application. The radar used in MARS is a side-looking airborne imaging radar, which makes use of the SAR technique, and includes an active phased antenna. These three characteristic features of MARS are explained in the following paragraphs.

3.3.1 Airborne imaging radar

An imaging radar works very like a flash camera in that it provides its own light to illuminate an area on the ground and take a snapshot picture, but at radio wavelengths. A flash camera sends out a pulse of light (the flash) and records on film the light that is reflected back at it through the camera lens. Instead of a camera lens and film, radar uses an antenna and digital computer devices to record its images. In a radar image, one can see only the light that was reflected back towards the radar antenna.

A typical radar measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths and polarisation's. At the Earth's surface, the energy in the radar pulse is scattered in all directions, with some reflected back toward the antenna, illustrated in appendix B.4.1. The system provides its own illumination and is therefore independent of other resources of illumination e.g. the sun. Furthermore microwaves are capable to penetrate through clouds, which results in a principle day and night operating capability and a high weather independence. The backscatter returns to the radar as a weaker radar echo and is received by the antenna in a specific polarisation (horizontal or vertical, not necessarily the same as the transmitted pulse). These echoes are converted to digital data and passed to a data recorder for later processing and display as an image. Given that the radar pulse travels at the speed of light, it is relatively straightforward to use the measured time for the round-trip of a particular pulse to calculate the distance or range to the reflecting object.

3.3.2 SAR, Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) is an active remote sensing technique, whereby radar pulses are transmitted from the radar instrument to the ground sideways the aircraft, and the radar echo's returned from the Earth are received again by the radar instrument. After elaborate calculations an image can be constructed from these echo's, representing a view from the aircraft of the Earth below (or more precise: sideways) the aircraft trajectory, but whereby clouds or darkness do not hamper the resulting image. Large areas of land or sea can be mapped in this way in a short time period.

The length of the radar antenna determines the resolution in the azimuth (along-track) direction of the image: the longer the antenna, the finer the resolution in this dimension. Synthetic Aperture Radar (SAR) refers to a technique used to synthesise a very long antenna by combining coherently signals (echoes) received by the radar as it moves along its flight track. In figure 3.2 the geometry of an airborne SAR is shown.

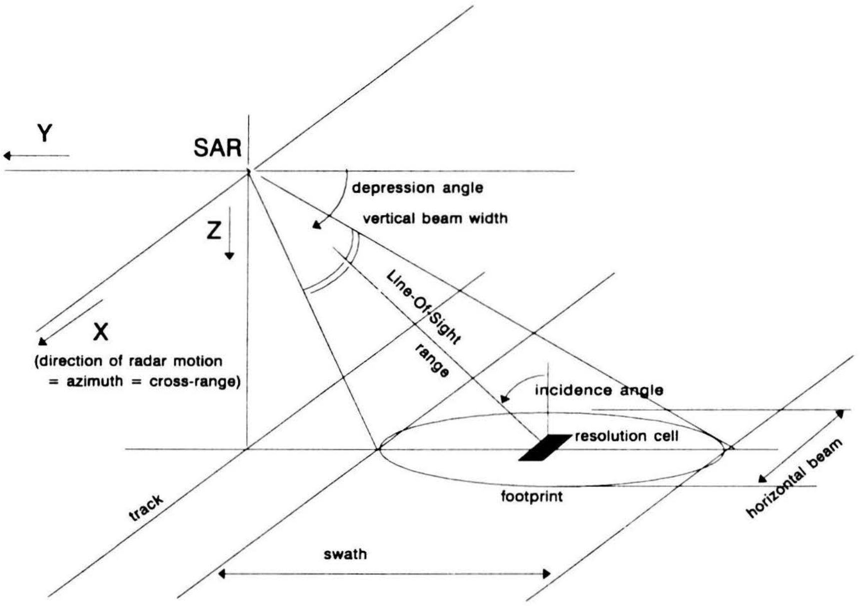


Figure 3.2 Geometry of an airborne SAR

The radar illuminates with its antenna beam a patch on the ground, to the side of the platform. By the motion of the platform, an illuminated continuous strip is formed, called swath. In the case of airborne imaging radar, the radar moves along a flight path. In appendix B.4.2 it is illustrated how the building up of a radar image uses the motion of the platform.

Aperture means the opening used to collect the reflected energy that is used to form an image. In the case of a camera, this would be the shutter opening; for radar it is the antenna. A synthetic aperture is constructed by moving a real aperture or antenna through a series of positions along the flight track.

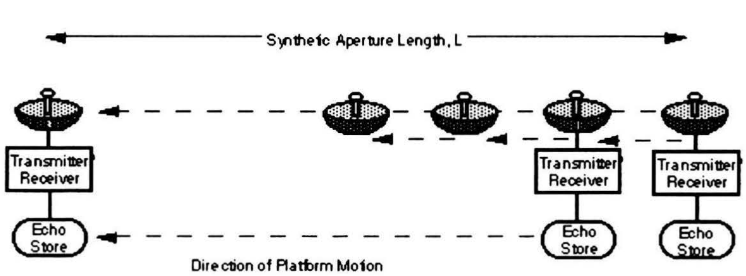


Figure 3.3 Constructing a Synthetic Aperture

As the radar moves, a pulse is transmitted at each position; the return echoes pass through the receiver and are recorded in an 'echo store.' Because the radar is moving relative to the ground, the returned echoes are Doppler-shifted (negatively as the radar approaches a target; positively as it moves away). Comparing the Doppler-shifted frequencies to a reference frequency allows many returned signals to be "focused" on a single point, effectively increasing the length of the antenna that is imaging that particular point. This focusing operation, commonly known as SAR processing, is now done digitally on fast computer systems. The trick in SAR processing is to correctly match the variation in Doppler frequency for each point in the image: this requires very precise knowledge of the relative motion between the platform and the imaged objects (which is the cause of the Doppler variation in the first place).

The pulse seems to scan the ground because the pulse hits the ground at different times. The pulse runs (scans) the ground along the swath. The pulse reaches the closest point first because this distance is shorter, and then runs until what the vertical beam width reaches. In figure 3.4 the scanning process is illustrated. With the knowledge of the time that pulse should reach the ground, the distance of objects to the radar can be calculated.

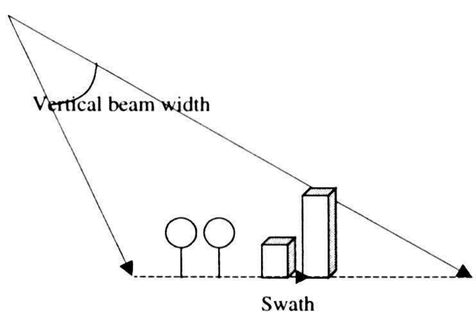


Figure 3.4 Scanning process

After processing, the strip is resolved into resolution cells, one of which is depicted in figure 3.2. A useful rule-of-thumb in analysing radar images is that the higher or brighter the backscatter on the image, the rougher the surface being imaged. Flat surfaces that reflect little or no microwave energy back towards the radar will always appear dark in radar images. In appendix B.4.3 the imaging of different types of surface are illustrated. The SAR processing converts the radar data into an image. An example of a PHARUS image is shown in appendix B.4.4.

3.3.3 Phased array antenna

One of the most prominent features of the MARS RADAR is its active array antenna. It is presently configured as a 2 x 24 array of active Transmit/Receive Modules. The use of a phased array enables electronic control of the beam direction and shape. The electronic steering allows compensation for the drift angle, which is caused by crosswind of the aircraft with the RADAR pod itself mounted rigidly on the aircraft. In appendix B.4.5 the effects of crosswind is visualised.

The antenna is composed of three Clusters of 2x8 elements. The cluster controller translates the antenna beam commands from Radar control to actual phase settings for the individual elements, thus performing as beam steering computer. In addition to the control of the phase of each radiator, in order to control the beam direction, the cluster control also calculates the required amplitude settings for each T/R-Module radiator, which controls the beam shape.

Control of both phases and amplitude of the radiated signal is achieved by using Vector Modulators in the active array.

The PHARUS active array features good polarisation decoupling, full polarisation operation (interleaved on transmit, simultaneous on receive), beam shaping (uniform or tapered excitation) and, through the use of a separate calibration channel, internal calibration.

These paragraphs show that several parameters affect the performance of the radar, which are:

- The pulse, which gives the time parameter;
- The frequency carrier, that carries the pulse to the ground;
- The chirp, which is a linear frequency (sweep) that codes the pulse, to calculate the Doppler effect in both directions;
- The incidence angle, which is the angle of the radar wave at the earth surface;
- The length of the antenna;
- Amplitude of the carrier;
- Attitude and Position system, existing of GPS and IMU.

These parameters are important for the FMECA because they affect the performance of the radar and therefore also the failure modes and the effects of the failure modes.

3.4 Conclusion

This chapter gives a theoretical scope for this research. The main topics are reliability, maintainability and the different characteristics of RADAR in MARS. From paragraph 3.1 can be concluded that reliability engineering is different for electronic, mechanical or software systems. From the second paragraph can be concluded that not one single maintenance development method can be selected for this research.

4 MARS system description

In this chapter a description of the MARS system is given.
In the first paragraph a general description of the MARS system is given. Furthermore the resources, which will be made available by BPPT, are given. In the fourth paragraph the functional descriptions of the different subsystems are given. In the fifth paragraph the physical and environmental conditions in which MARS will operate are given. In the last paragraph descriptions of the potential future upgrades are given.

4.1 MARS

MARS will lead to an operational End-To-End system focusing on the advantages of the airborne Synthetic Aperture Radar (SAR) techniques. The MARS project aims at improved sustainable management of natural resources (e.g. forest monitoring) in Indonesia.

The MARS project will be derived from an existing technology developed in the PHased ARray Universal Synthetic aperture radar (PHARUS) instrument. The PHARUS instrument employs the advanced active phased array antenna technique. The active phased array technique results in the feature that the direction of the transmitted pulse can be steered electronically to compensate for unwanted but always existing aircraft motions.

4.2 Resources made available by BPPT

The following resources will not be provided by Fokker Space, but will be BPPT responsibilities:

- Selecting and making available of an appropriate aircraft, including required interfaces;
- Providing inputs to platform-specific modifications;
- Sensor-aircraft integration, functional validation of the complete airborne measurement system;
- Certification of the aircraft-MARS combination according to Indonesian law
- Pilot training;
- Familiarisation campaign and related data processing;
- IT infrastructure thematic processing;
- Ground transport of collected data.

4.3 Functional description

MARS consists of two main parts, the flight segment and the ground segment.

- The flight segment consists of a radar system in a pod mounted under an aircraft and a data acquisition and data storage system inside the aircraft. In the aircraft pre-processing of the data will take place. Pre-processing consists of digitising, reduction and storage of data on harddisks. On ground data preparation system converts the data from the harddisks to RAT, Redundant Array of Tapes.

- The ground segment consists of a Parallel PC network where several Generic Sar Processors (GSP) are installed. The GSP's process the raw data into digital images.

The block diagram of the MARS system is given in figure 4.1. The systems given in the blocks with a white background are part of the MARS project. The items given in the blocks with a grey background are assumed to be available in Indonesia and are not part of the MARS project.

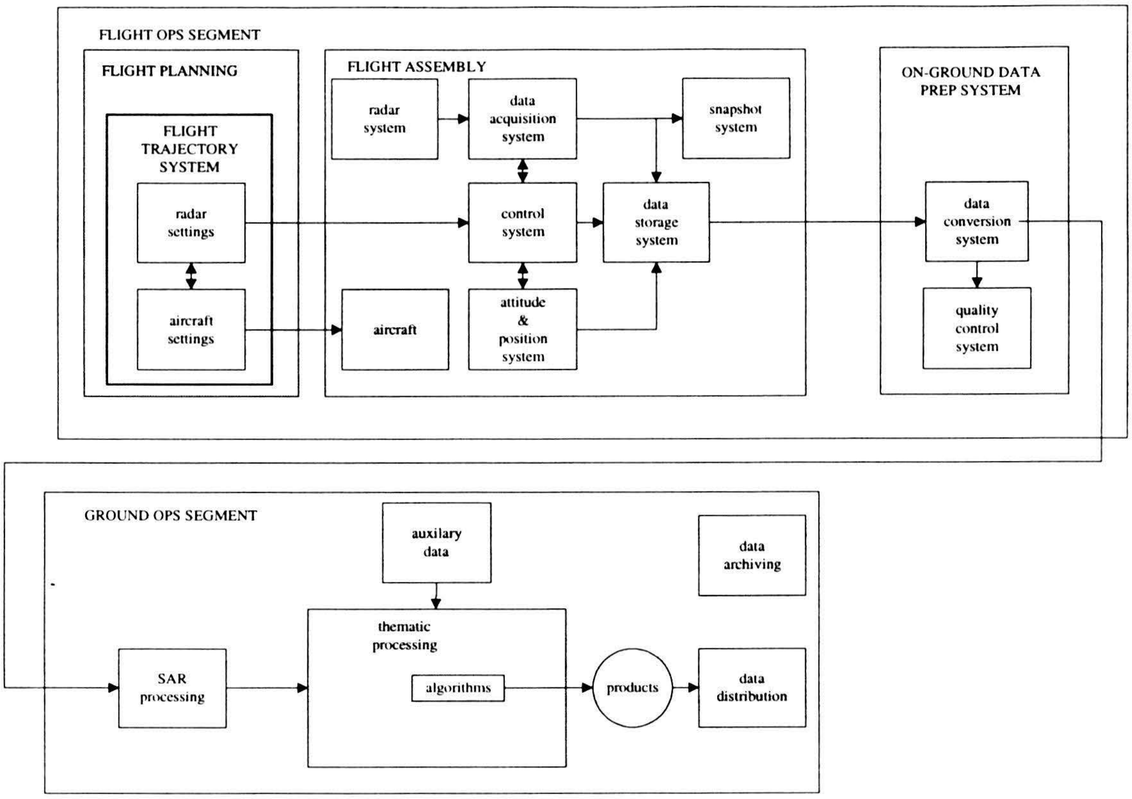


Figure 4.1 Block Diagram of MARS

The content and the function of the blocks on unit level are described in the following paragraph. The unit block diagrams of these systems are given in Appendix C.

4.3.1 Flight segment

The flight trajectory system is part of the flight planning and defines the radar settings and aircraft settings. The aircraft settings (like speed and pitch) must be communicated to the pilot. The radar settings are communicated to the operations systems for control of the radar and data acquisition system. The block diagram is given in appendix C.1.

The radar system is housed in a pod below the aircraft. Radar signal generation, radar signal transmission, and signal reception are the major functions of the radar system. The temperature control subsystem of the radar system ensures a constant operating temperature of the radar electronics at the operating altitude. The most important parts of the radar are the microwave Transmit/Receive modules. The MARS system contains 48 of these modules. Each module contains a small 20-Watt radar with a selectable transmit polarisation (H or V) and two parallel receivers for the two receive polarisation's (H and V). The active phased array antenna is self-calibrating, and each T/R module contains a separate calibration channel. The internal calibration of the radar phased array eliminates phase errors and variations in the transmit power and receive amplification. The block diagram is given in appendix C.2.

The data acquisition system contains the electronics for the digitising, pre-processing, and the formatting of the radar and navigation data. The block diagram is given in appendix C.3.

The Control System constitutes of:

- Control Panel, which is a user interface to control and monitor the measured data;

- Dedicated microprocessor software that controls several functions between the data acquisition system and radar system.

The block diagram is given in appendix C.4.

The data storage system stores the data on board the aircraft and uses high-speed data storage devices.

The attitude & position system produces information of the flight trajectory and the position of the aircraft, which is needed during the on ground SAR processing to compensate for the movements of the aircraft. The information comes from the built-in (Differential)-Global Positioning System and Inertial Measuring Unit sensors installed inside the aircraft.

The snapshot system is used as an image quality control. During the flight the system will offer quality control of the received radar data by means of snapshots.

The on ground data preparation system will be housed at or near the temporal campaign base of the aircraft. The stored raw SAR and flight data are read by devices of the facility, will be pre-processed, and will be transferred to long storage media. The On Ground Data Preparation System will provide a review of the success of the last SAR data recording, before the next aircraft flight is scheduled. The medium for the output data will be magnetic tapes, today still the most cost effective storage "long-term" medium. The recording unit will be based on a Redundant Array of Tapes (RAT) architecture. The block diagram is given in appendix C.5.

4.3.2 Ground segment

The ground system is not a part of the research but is shortly described to get a good overview of the whole MARS system.

SAR processing

The SAR processing consists of a number of consecutive actions, and will be implemented in a parallel architecture. After reading the tapes from the on-ground data preparation system, and the execution of some data correctness checks, the data is prepared for range and azimuth correlation. The block diagram is given in appendix C.6. The architecture used for the SAR Correlation task is highly parallel and is performed by the use of computer "clusters" that are connected to a Master Controller Unit. The block diagram is given in appendix C.7. This Master unit is responsible to dispatch the SAR data to be processed and "harvest" the correlated data, while each Parallel Process Unit (Slave) is responsible to perform the azimuth correlation on the data chunk that has been received by the Master Unit. These intensive calculation jobs are executed on so-called data chunks, the jobs distributed over the connected PC-s. The SAR processing is carried out by splitting the original data set into chunks of data that can be processed independently by dedicated PC-based units that will be responsible for different parts of the process chain.

The data from the flight Attitude and Position System are used in the processing to calculate the necessary motion corrections on the obtained SAR data.

4.4 Physical and environmental characteristics

The MARS system is designed to work under flight conditions with an outside temperature as low as – 55° C.

The Data Acquisition, Data Storage and Control System are designed to work under the following operational conditions:

- Temperature range 5° to 40° C
- Humidity maximum 80% non condensing
- Above 10.000 ft: pressurised cabin

The On Ground Data Preparation System will operate with a temperature range from 10° to 40° C and a humidity which ranges from 20 to 80% non condensing.

4.5 MARS upgrades

The MARS system will be designed with an open architecture. This means that MARS allows upgrading. The extension of MARS is envisaged as follows:

Add single pass interferometric capabilities (MARS-2)

- A second antenna will be added. With this second antenna, interferometric measurements will be possible. MARS-1 can only measure distance, while MARS-2 will also be able of measuring height of objects on the ground.

Increase system bandwidth and radar power (MARS-3)

- The resolution will be increased. With a higher resolution the radar will be capable of recording the 3-dimensional shape of single trees, while MARS-1 averages out the input data of a number of trees or objects because the resolution is not large enough.

4.6 Conclusion

This chapter described the MARS system. The MARS system will be a copy of the PHARUS system and is now in the re-engineering phase. This research concentrates on the flight segment of MARS.

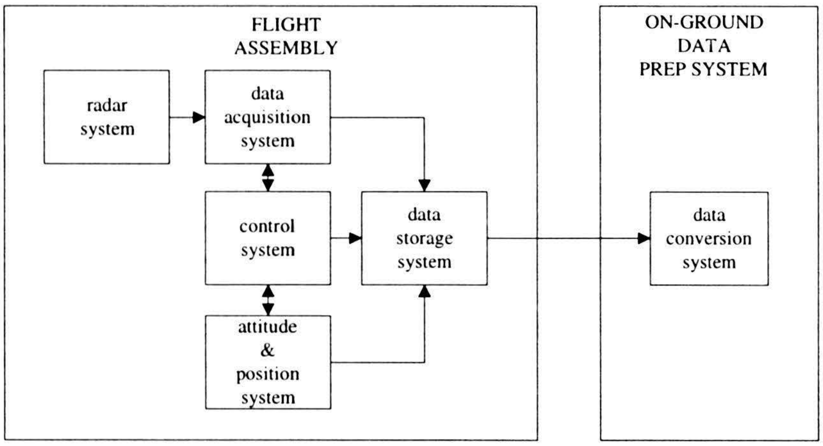


Figure 4.2 Parts of MARS, which are part of this research

Some changes are made because of the different application and different environment the system will operate in. The PHARUS is described in the next chapter to make clear what the differences and use of PHARUS is. The mission profile, RAMS analyses and the maintenance concept, which are described in the next three chapters, also focus on the flight segment of MARS.

5 PHARUS system

This chapter describes how PHARUS is different from MARS. It furthermore describes how PHARUS is used and what the failures are that occurred in PHARUS.

5.1 Differences between MARS and PHARUS

MARS is different from PHARUS. The differences are divided in system- and user differences and are described below:

System differences

1. Harddisks instead of tapes;
2. The on ground data preparation system is different, because in MARS it is a system that converts the data from harddisks to tapes, and in PHARUS it is a system that converts the data from airborne tapes to computer tapes.
3. Different components if necessary because of re-engineering.

User differences

1. Environmental circumstances (tropical conditions);
2. Cultural circumstances;
3. PHARUS is used for all sorts of applications and MARS will be used mainly for forest monitoring.

5.2 Use of PHARUS

MARS will be used differently then PHARUS. PHARUS made the first flight in September of 1995. PHARUS flew several campaigns in the Netherlands and Germany. The campaigns flown by PHARUS consisted of 3 flights on average, so the PHARUS campaigns are shorter than the expected MARS campaigns. Of course one difference is that the surface areas in the Netherlands are relatively small compared to Indonesia, where the forest takes up an enormous part of the country. PHARUS is approximately used 600 hours in 4 years. Read more about PHARUS and the flights of the last years on the webpages of TNO-FEL on PHARUS [27].

5.3 Failures of PHARUS

This paragraph describes the occurred problems and failures of PHARUS. The information is derived from the PHARUS logbook, kept by TNO-FEL. I have included this paragraph in my report to show what the occurred failures in PHARUS were in the last 4 years.

The failing of flights was mostly dedicated to human errors or bugs in the operating software. If the controller does not install the systems accurately then the systems do not work appropriate. It is not always visible that the systems are not installed in the right way. A real time processor, which can process data and immediately produces an image, can prevent the failure of a whole flight.

The biggest problems with PHARUS occurred in the integration between hardware and software. A lot of problems occurred in the communication between the radar system, control system and data acquisition.

During the time PHARUS was used in the last 4 years, failures occurred in all sorts of unexpected and expected systems.

- Cluster control (Club), broken printed circuit board;
- Cooling system was leaking;
- Hoses of cooling system were porous;
- Expansion tank replaced;
- DRO-PLL, (a component in the frequency generator), is broken because of under heating;
- Motor of cooling system was corroded;
- T/R modules, approximately one every year; mostly caused by weak bondings.

So only one Club and the DRO-PLL failed in the past 4 years. So for the electronic systems, corrective maintenance is the most effective maintenance task because the failures in the electronic systems occur randomly.

5.4 Conclusion

The purpose of this chapter is to make clear that MARS and PHARUS are different and what the results of PHARUS are in means of failures. I concluded that because the failures occur randomly, corrective maintenance for the radar system is the most effective maintenance policy.

6 Mission profile

In this chapter, the mission profile of MARS is described. A mission profile is set up because the requirements, which are set by BPPT, are not sufficient. Therefore a mission profile is described in this chapter and is based on a combination of what is legally required, what the capability of MARS is, what is expected by Fokker Space and what is necessary to map the forestry of Indonesia. As a result of these four different uses of MARS, a most likely scenario of the application of MARS is described.

The expected scenario is described in the first paragraph. The operational plan of MARS is described in the second paragraph. In the third paragraph, an estimation of the operational time is made.

6.1 Scenario MARS project

A scenario of the application of MARS is described based on the following knowledge:

- System knowledge of MARS, and possible application of MARS, as derived from interviews held with system designers of PHARUS and MARS;
- Knowledge of experts of the remote sensing group and MARS project team of Fokker Space;
- Knowledge of the common application of forest monitoring (see appendix D.1).

The assumptions taken in this chapter are also based on these three sources of information.

BPPT did not give a requirement of how many flights MARS should be able to make. As a result of this, an estimation is made of the most likely scenario of the MARS application. In consideration are taken the following four options:

1. How many flights are necessary to map the forestry of Indonesia?
2. How many flights are possible for MARS?
3. How many flights are legally obliged?
4. How many flights will most probably be made?

Ad 1. MARS is capable of mapping 3000 km^2 per hour with a swath of 8 km. In one flight 15000 km^2 can be mapped because MARS can perform 5 hours of effective acquisition per flight. The total area of Indonesia covers 1.950.000 km^2. The tropical forests take around 75% of Indonesian country. This counts for around 1.462.500 km^2 of forestry. In order to map the whole forest area, at least 488 hours of raw flight data has to be acquired. So a minimum of 98 flights are necessary to map the whole forestry of Indonesia.

Ad 2. MARS is capable of making maximal 90 flights a year, including SAR processing to images [3].

Ad 3. A new law has been introduced recently which implies the following: Legally 20 million-hectare of forest have to be mapped every 5 years with a remote sensing system, look for more details in paragraph 2.2, page 4. If you convert 20.000.000 hectare to the numbers of flights to map this area, 30 flights have to be made every 5 years. So the minimum use of the MARS system is 6 flights a year. In the future this number will increase, because the international laws on forest monitoring will be expanded and will be more rigidly enforced.

Ad 4. It is not probable that the total forestry will be mapped in one year, but it is more likely the mapping will be done in parts. These parts are called campaigns. The campaigns last around 3 months and are meant to map a specific area and register changes of the area. Probably there will be two campaigns in one year. The campaigns will be intensive which means there will be flights every other day. In the time between the campaigns, the results will be thematically processed. There is a possibility that campaigns can be shortly interrupted by other calamities. The MARS system is then needed at another place, e.g. if forest fires or if other disasters like plagues occur. Assumed is that the MARS system will probably have a life cycle of ten years. This assumption is based on what are usual and acceptable lifetimes in this industry and what the application and use of the radar system is.

A most likely scenario will be 2 campaigns a year of approximately 30 flights. So a total of 60 flights a year will be probably made. For more details look at paragraph 6.3, where an estimation of the operational time is given.

This fourth scenario will form the base for the operational lifetime, as described in paragraph 6.3. From this scenario the RAMS analysis will be done. The campaigns take up only 6 month out of one year.

6.2 Operational plan

The following paragraph describes a typical operations timeline for the MARS system. This operational timeline is derived from the MARS system description [2], from Fokker Space. In the appendix D.2 an example of a typical operations timeline is given and it illustrates the following activities.

__Flight segment__

Pre flight
At the home base the preparation of a campaign starts with pre-flight activities. It includes activities for flight trajectory planning and preparation of the transport of the applicable MARS-1 equipment, as the radar pod, to the campaign base.

On the airfield (campaign base) from which the flights during a specific campaign would depart, the equipment for On-Ground Data Preparation would be installed. The size of this equipment is such that it can be transported to the airfield with the aircraft used for the measurement campaign.

Measurement flight
A full flight is assumed to have a maximum duration of 7 hours of which 5 hours effectively could be used for measurements.

The Control Panel that is used to monitor and control the radar is based on a PC configuration. The interface provides full access to all the radar functions. It is programmed on the ground with the flight planning data. Optionally the Control System provides the operator the possibility to check on-line the quality of the received radar data.
Radar measurement data and navigational data are stored on high-speed storage devices. All devices, needed for the storage of data collected during one flight, can be mounted before take-off in the Data Storage System.

Post flight
After return to the campaign basis the devices on which the measurement data have been recorded are removed from the Data Storage System. Since the devices will be mounted in special racks, which enable easy dismounting and mounting, this will be a fast and simple operation.

Data conversion
- The devices with measurement data are subsequently mounted in the computer for On Ground Data Preparation and the measurement data is transferred to long-term-storage-devices.
- During the transfer the On Ground Data Preparation enables the operator to perform quality control of the data by using the snapshot capability.
- The operator should generate quality reports to demonstrate that the flight has been successful.

The whole process of data transfer can be finalised in a time period such that the recording-devices can be reused for their next flight. The transport of the long-term-storage-devices to the MARS processing facility will be the consecutive step before the radar data processing can start.

Ground segment

Radar data processing
In the MARS Processing Facility the SAR processing will take place. The computer capacity of this facility will be such that the SAR processing of the data of one flight can be finished within a period of nominal 48 hours (based on the assumption that the aircraft will have a maximum of 90 operational flights yearly).

Thematic processing
The thematic processing of the image data will take place off-line by the specialists of the locally thematic processing organisations. Long term archiving and provision of back-ups will be the responsibility of BPPT.

6.3 Estimation of operational time

Several assumptions are made for a realistic but probably overrated estimation of the operational time of a campaign, and the total operating time for the flight assembly of MARS. The assumptions are based on the sources described in paragraph 6.1.

- Two campaigns a year, of 3 months (5*4*3=60 working days)
- Every other day there will be a flight, so 30 flights per campaign
- The flight assembly will be used 5 hours per flight * 30 = 150 hours
- 10% of the time the radar is used for pre-flight checks etc. Total of 165 hours per campaign, the radar will be in an active operating phase.
- MARS will operate for 10 years with approximately 2 campaigns a year. So, this counts for a total of 20 campaigns with 20*165 = **3300 hours of total operating time**.
- The on ground data preparation system converts the data from the harddisks to tapes. The conversion costs less then 5 hours.
- The ground system is not part of the research and has no influence on the flight assembly. The active interpreting and further processing and comparison of images will take place in the rest of the year.

The total operating time of the flight assembly is 3300 hours during these ten years. This figure will be used to determine the reliability of MARS radar system.

The MARS system will probably be used less than described above. But the time is overestimated to give a worst case scenario for the operating time.

6.4 Conclusion

This chapter describes what the objective and operational use of MARS is. Furthermore it is described what the different scenarios and application of MARS could be. The different scenario's lead to an estimation of the total operating time and the operating time of one campaign. The operating time is overestimated to take a worst case scenario as a starting point. With the aid of these figures the reliability prediction of the PHARUS system is made.

The next chapter describes the RAMS analyses, which are executed to see if the objectives of MARS can be reached with the existing system.

7 RAMS analysis

In this chapter the RAMS analyses, Reliability-, Maintainability-, Availability- and Safety analyses will be described. Every paragraph will consist of a description of the purpose of the analysis and the used tools and methods that are carried out for the analysis. Besides that, the conclusions are described for each analysis. The implementations of the used tools are included in appendix E. This analysis will form the foundation for the maintainability concept.

7.1 Reliability analysis

In this paragraph the reliability of the radar system of MARS is given. It is the prediction of the reliability of the radar system based on the military standard of electronic systems [14]. Furthermore the allocated reliability requirement of the subsystems of the flight segment is calculated [23].

Three kinds of reliability can be distinguished, namely:

1. Predicted reliability = Reliability is predicted with the aid of the reliability's of the components;

2. Required reliability = Reliability that is required by the customer;

3. Actual reliability = Reliability as derived from operational field data.

Because not enough field data is available, the actual reliability can not be calculated.

The purpose of a reliability analysis is to analyse the performance of the different units of the PHARUS system and it makes visible how much functionality remains after one or more failures.

7.1.1 Reliability requirements

BPPT in Indonesia did not set a reliability requirement for the MARS system. So a target has been determined for the reliability of the flight segment. The achievable reliability is set on 0.95 for one campaign, 165 operating hours. A reliability of 0.95 implies that two failures a year will occur. The reliability of the radar system in proportion to the complexity of the radar systems gives a ratio for reliability to complexity. With the aid of this ratio, the reliability of the other subsystems of the flight segment can be allocated. The reliability allocation is described in paragraph 7.1.3.

7.1.2 Reliability prediction

To calculate the reliability of the flight segment, a reliability prediction is made. The prediction shows the reliability and performance of the radar system. Before the reliability prediction is calculated, first the Functional Block Diagram and the Reliability Block Diagram are made.

1) **Functional Block Diagram**
   FBD is very useful to make the unit- and component interfaces, data- and command flows visible. The separate functional block diagrams of the subsystems of the flight segment

are included in Appendix C.1- C.5. Appendix C.6 and C.7 show the FBD of the ground segment.

2) **Reliability Block Diagram**
RBD is different from the FBD in the sense that the RBD does not focus on the design aspects, but makes visible how much functionality remains after one, or more failures. The RBD from the radar system and the subsystems of the flight assembly are shown in Appendix E.1.2.

3) **Reliability Prediction**
The reliability of the radar is predicted with the use of failure rates from the MIL-HDBK-217F and operating time of 3300 hours. The predictions of the radar system are based on failure rate data of the PHARUS from TNO. TNO made a reliability prediction based on a parts count. The failure rates of the parts come from the MIL handbook 217E, with a temperature of 50 °C and stress factor of 30%. The environmental condition is A_{IC}, Airborne, Inhabited and Cargo. This MIL handbook 217E gives a reliability prediction of electronic equipment. The prediction is shown in appendix E.1.4. Appendix E.1.4 includes the reliability prediction of the RADAR system over the total operating time (=3300 hours), one campaign (=165 hours) and over one mission, (=5 hours). The next table includes all the reliability figures, which are derived from the reliability prediction.

System	Failure rate (λ)	MTBF	R(5)	R(165)	R(3300)
Radar	79.79	13.930	99,96%	98,82%	78,91%

Table 7-1 Reliability figures

The top four units with the lowest reliabilities on 3300 hours are the following:

1. T/R module (R = 0.442)
2. Frequency generator (R=0.959)
3. Chirp generator (R=0.971)
4. Cluster control (R= 0.978)

T/R modules
The T/R modules are the most expensive and most important parts of the MARS system. The radar contains 48 T/R modules and the influence of one broken T/R module is very small. The overall system performance degrades gradually with the number of defective T/R modules. The performance degradation is not linear. The performance of the radar is defined as the resolution or the capability of the radar to distinct objects. The failing of the first few (approximately 1-5) T/R modules does hardly have an impact on the digital images. An absolute figure for the performance degradation can not be calculated. For MARS no requirements are given for the quality of the images. Forest monitoring is assumed to be the application. The performance of the radar system is also dependent on the object that is observed. Therefore it is not possible to quantify the performance degradation of the radar system. The required resolution is dependent on the objective of the flight; e.g. do you want to distinguish trees, or buildings, ships, moving targets etc. For smaller objects a higher resolution is needed.

For the application of forest monitoring it is assumed that 90% of the T/R modules must work to get the appropriate performance to make useful digital images. So the failing of 5 T/R modules is allowed. For other application like coastal monitoring or forest fires monitoring less performance is needed. Another parameter that influences the performance is the location of the T/R modules. The T/R modules, which are located in the middle of the radar, influence the performance of the radar more than the T/R modules at the side. The radar itself detects failed T/R modules. If a failed T/R module is detected then the radar does not stop working. So the radar system can be used with non-working T/R modules.

With a detailed research it is possible to calculate the performance of the radar by simulating the behaviour of failed T/R modules and knowledge of SAR processing. For this research an assumption is made that 5 failed T/R modules is the limit for forest monitoring.

Two recovery actions are possible to compensate for the failure of T/R modules. One solution to compensate for the degraded performance is to provide the T/R modules next to the failed module extra power. In this way the nearest T/R modules compensate a little bit for the absence of a T/R module. Another possibility to compensate for the degraded performance is to lower the altitude, if it is possible. The performance is better but the scanned surface will be smaller. In the next table it is visible how much the altitude must be decreased to achieve approximately the same performance, and what the decrease of the scanned surface is with this flight altitude.

Number of failing T/R modules	**Flight altitude decrease (nominal altitude = 8 km)**	**Surface decrease (nominal surface = 50 km^2/hr)**
0 T/R module	8.000	50.000
1 T/R module	7.510	46.940
2 T/R module	7.041	44.007
3 T/R module	6.592	41.199
4 T/R module	6.162	38.513
5 T/R module	**5.751**	**35.946**
6 T/R module	5.359	33.496
7 T/R module	4.986	31.160
8 T/R module	4.630	28.935
9 T/R module	4.291	26.819

Table 7-2 Flight altitude and scanned surface decrease

The T/R modules are made by TNO, and require knowledge of high frequency and microwave technology. If it is not possible to repair the module in Indonesia then it must be done by TNO in the Netherlands. Two spare parts of the T/R modules are provided, because these units are the most complex units and the hardest to repair.

If a T/R module is replaced then the radar itself will change the calibration characteristics of the module. This is necessary because the T/R modules are not identical but should behave as if they are identical, because together they should behave like one antenna.

The reliability of one flight (5 hours) = 0.99964, which is very high. The failure rate is calculated with a total failure rate of the radar system of 71,79 per million hours, see appendix E.1.4 So no extra measures (e.g. redundancy) have to be taken to prevent the radar from failing.

MTBF

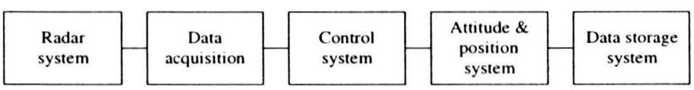
The MTBF for the MARS radar system of the flight assembly has been calculated using the reliability prediction. The reliability of the radar is 79 % for 3300 hours, (see appendix E.1.4). The total failure rate is71,79 per million hours.

$MTBF_{MARS}$ = 13.930 hours, implies 1,6 years, (calculation see appendix E.1.4)

13.930 hours is 4,2 times the total lifetime of the MARS system.

7.1.3 Reliability requirement allocation

For the subsystems of the flight assembly the reliability requirement allocation is made [23]. The table with the results is shown below and the table with the calculation is included in appendix E.1.5. The allocation of the reliability is made with the aid of complexity factors. The next diagram shows what the complexity factors of the five systems comparatively are. The radar system takes up 50 % of the reliability of the flight assembly. From the reliability prediction of the radar system and the complexity factor, the reliabilities of the other subsystems can be allocated.



50 : 15 : 25 : 3 : 7 =Σ100

Figure 7.1 Complexity comparison of flight assembly

The figures are calculated with the allocation of requirements according to Blanchard, [23]:

Subsystems	Allocated reliability on 165 hours	Allocated reliability on 3300 hours	Complexity factor
Radar system	0.98822	0.78906	50/100
Data Acquisition system	0.99646	0.9367	15/100
Data storage System	0.99835	0.9704	7/100
Attitude & position system	0.99929	0.9873	3/100
Control system	0.99411	0.8945	25/100
Total reliability flight assembly	0.9766	0.6335	1

Table 7-3 Minimal reliability requirements for subsystems of flight assembly

The total reliability of the flight assembly is 0.9766 on 165 hours. A reliability of 0.977 implies that in one year, one flight fails. The reliability requirement of 0.95, see § 7.1.1 is reached.

During the passive period, the failure rate is assumed to be zero, because the system exists merely of electronic system. Assumed is that electronic systems do not degrade in the passive period. So the passive period does not have an influence on the RADAR, as long as the RADAR is stored in an air-conditioned area.

7.1.4 Conclusion

The reliability of the radar is 0.79 % for an operating time of 3300 hours, (see appendix E.1.4). In the next table is shown what the reliability is of the radar system and flight segment for 5, 165 and 3300 hours.

System	Failure rate (λ)	MTBF	R(5)	R(165)	R(3300)
Radar	79.79	13.930	99,96%	98,82%	78,91%
Flight Assembly	143.58	6.965	99,93%	97,66%	63,35%

Table 7-4 Reliability figures radar and total flight assembly

The requirement of the MARS flight assembly of 0.95 is met if the other subsystems, (Data Acquisition System, Data Storage System, Control System and Attitude and Positioning System) have the allocated reliability, see table 7-3.

7.2 Availability analysis

Availability has a strong relation with time. MARS does not operate the whole time. A year has approximately 2000 operating hours (5 days*8 hours* 50 weeks), and MARS operates 330 hours a year, see §6.3. So MARS operates 16.5 % if the total time. Time and therefore availability is not critical for this system. Legally 20 million hectare has to be mapped every five years with the aid of a remote sensing system. For more details see paragraph 2.2. Converted to flights, it means 30 flights every five years. So the minimum use of the MARS system is six flights a year. A maximum of 90 flights a year can be reached, assuming no downtime is taken in account. So time and availability are not drivers for the maintenance concept. In the next paragraph the different availabilities that can be distinguished are described.

The purpose of the availability analysis is to predict the system availability from the failure- and repair data. Availability is useful for the operational phase of a system.

7.2.1 Availability for MARS

Different availabilities can be distinguished, which are the following [21]:

1. Inherent availability = MTBF/(MTTR+MTBF), which only takes in account the corrective maintenance;

2. Achieved availability = MTBM (Mean Time Between Maintenance) /(MTTM (Mean Time To Maintenance)+MTBM), which takes in account corrective and preventive maintenance;

3. Operational availability = MTBM/(MDT (Mean Down Time)+MTBM), which takes in account corrective and preventive maintenance and also down time because of organisational circumstances;

4. Steady-state availability = UPTIME/(UPTIME+DOWNTIME), which concerns the availability in a certain period.

The availability for MARS will be described by the inherent availability because the downtime caused by failures, which needs corrective maintenance, is the main problem for MARS. Scheduled maintenance, as well as preventive maintenance will be very low, and will be mainly done in pre-flight checks.

7.2.2 Conclusion

Time is not a driver for the MARS system because the system does not have to be available all the time. The radar system is used 16.5 % of the available time for operation. If time was a driver then the maintenance concept must be different. The down time must then be minimised. But for MARS minimisation of down time is not necessary.

7.3 Maintainability analysis

In this paragraph the maintainability of MARS is described. Maintainability can be approached from a qualitative manner and also from a quantitative manner. Both are described in the following paragraphs. The purpose of this maintenance analysis is to identify maintenance critical items, and how the system can be optimally maintained.

Maintenance can be divided in:

- Preventive maintenance is to prevent the system from failing.
- Corrective maintenance: to repair a failed system.

Preventive maintenance for electronic systems is impossible. The calibrating of electronic systems is possible to keep the systems to work within specifications. The calibration of electronic systems is not considered as a preventive maintenance action but as a functional test. The preventive and the corrective maintenance policies together describe the maintenance concept. Preventive maintenance can be further divided in time- or condition based maintenance, see § 3.1.2.

7.3.1 Qualitative maintainability analysis

The qualitative maintainability analysis for this research consists of a FMECA, see the next paragraph. Another analysis, which is done, is a maintenance identification, see Appendix E.2.3. This analysis investigates per unit if the failures are detectable, should the action be repair or replace, if it is a long lead item and whether the item needs preventive or corrective maintenance.

7.3.1.1 FMECA

FMECA is the Failure Modes, Effects and Criticality Analysis and starts by identifying the functions of components. Subsequently the safety- and reliability effects and propagation of the failure to higher levels are determined. As last part, the probability of each failure is determined. The failure probability of the units is derived from the reliability prediction in Appendix E.1.4. FMECA identifies the maintenance critical items of PHARUS, on which the maintenance concept must concentrate.

The FMECA for this research serves more as a description method for MARS. It reflects in a structured way the total system in which all system functions and failure modes become clear. FMECA is included in appendix E.2.2. A column with preventive and corrective maintenance is included in the FMECA. Not all columns are filled out because not all the information is available.

To make a FMECA, detailed system knowledge is required. So a person who developed the system and who has sufficient system knowledge should fill out the FMECA. It was not possible to fill out the FMECA with the help of a design and system expert. So for this research I set up the FMECA myself, which is a functional FMECA.

7.3.1.2 Maintenance identification

Maintenance identification is done to complete the maintenance analysis. The maintenance identification analysis identifies all the maintenance aspects, which are important for the MARS system. This maintenance identification table is included in appendix E.2.3. All the important aspects like: type of maintenance, replace and repair time, tools and equipment, critical units, kind of maintenance policy, of MARS are included in this table. Some information is not available. The subcontractors of MARS must include this information when they deliver the systems. I used the decision diagram, included in appendix F.2 [19], to determine per unit whether preventive or corrective maintenance is needed. The results are included in the maintenance identification table.

7.3.2 Conclusions qualitative maintenance analysis

The FMECA for MARS gives a functional description of the system and can be a driver for the design of MARS and the maintenance operations. This analysis determines which parts of MARS are the most important to look at. The critical parts lead to the failing of the total system. So MARS is subdivided in terms of failure in the flight assembly and the remaining systems. All subsystems of the flight assembly lead to a critical (serious) failure.

The MARS system contains common modes and common causes (CM/CC). CM/CC's are failure modes or failure causes that can cause a failure in all units and subsystems. The following CM/CC's are determined:

1) Electrical;
2) Vibration;
3) Temperature.

The radar system is designed for airborne conditions, this implies that the radar system is protected for temperature changes and vibrations.

Furthermore, the radar turns off, when powers are provided that are too high or too low. Communication and power (electrical) problems are covered by a BIT (Built in Test). So it will be made visible on a control panel in the aircraft that the control system does not work properly and/or that the power supply does not work properly. The RADAR will automatically switch to the safe mode, which is OFF. This is because some units can get damaged by too high voltages.

The following failures can lead to catastrophic, serious or major failures, see FMECA (appendix E.2.2):

- Leaking of pod;
- Breaking of mounting points;
- Failure of cooling system, if not detected by the temperature sensors.

See the safety analysis in paragraph 7.4 for a more elaborate description of the failures and consequences.

The following failures of units lead to serious failures, which means a loss of mission (see appendix E.1.4) and fail with a probability $>10^{-5}$;

- Chirp generator;
- Frequency generator;
- Cluster control.

The failures occur random, so no preventive maintenance can be done.

For the flight segment it is determined what parts allow corrective maintenance and what parts require preventive maintenance. How to determine what maintenance policy is allowed or required is visualised in the flowchart in appendix F.2.

1. **Corrective maintenance** for electronic systems:
   Radar system, data acquisition system, data storage system, control system, attitude and positioning system and the on ground data preparation system.

2. **Preventive maintenance** for mechanical systems:
   The housing of the radar system, so the pod and cooling system.

For a more elaborate description, see chapter 8. In chapter 9, conclusions and accompanying recommendations that belong to the above conclusions are suggested.

7.3.3 Quantitative maintainability analysis

A quantitative maintainability analysis is not carried out. It was not possible to collect the information of repair times and costs of the different units and subsystems. For the quantitative maintenance analysis a prediction of the Mean Time To Repair has to be made. So for all units and subsystems, like they are included in the FMECA, a MTTR, Mean Time To Repair, must be estimated. What the time to repair includes is described in paragraph 3.1.2.

A maintainability prediction for hardware consists of determining the MTTR of the units. With this prediction the optimal maintenance-, inspection intervals and the required number of spare parts can be determined.

7.3.4 Conclusion quantitative maintenance analysis

The quantitative analysis can not be done, because no information regarding the repair time of units can be given. When the MARS system is used in Indonesia, the repair times should be recorded. With the aid of the failure registration the maintenance concept can be amended according to the maintenance need of the radar system.

7.4 Safety analysis

The purpose of safety engineering is to ensure during all the phases of the system lifetime, under both nominal and accidental conditions, that the systems characteristics do not give rise to one of the consequences specified by the applicable "consequence severity table". The severity categories cover the following events:

1. Loss of life, permanent disability of personnel, population;
2. Loss of system, or extensive damage of system;
3. Long term environmental effects.

The human interface with MARS is limited, therefore safety for MARS is not very important. Nevertheless in every system safety items come foreword. The safety analysis for MARS has been focused on some incidents that could happen and are derived from the FMECA, see appendix E.2.2. The incidents belong to the three categories of safety, which are mentioned above. Furthermore a hazard analysis is done to identify other catastrophic events. The hazard analysis is included in appendix E.3.1. The catastrophic failures that come from the hazard checklist are covered in the safety analysis as well, and are referred to with a hazard code. Also the FMECA entry is referred to with a code as included in the FMECA.

Ad 1. Loss of life, permanent disability of personnel, population:

- The pod has a weight of 250 kg. The mounting points between pod and aircraft can break. If it falls down when it is in operation, it is a catastrophic failure. The pod could injure or kill a person or damage an object, and probably be severely damaged itself.

  The pod is designed by the NLR and manufactured by TNO-FEL. The pod for MARS will be an exact copy of the PHARUS pod. The NLR tested the PHARUS pod according to the RLD safety program (Rijks Luchtvaart Dienst = Dutch Civil Aviation Authority) for safety in airborne inhabited conditions. Otherwise it is not allowed to fly with 250 kg mounted under a plane. So these safety aspects will not need further investigation. Also see the hazard codes AA and AF in the hazard checklist in appendix E.3.1 and the FMECA entry is 17.

  "RLD has a preventive safety policy. The starting-point is that all aviation activities are forbidden, unless proved that the activities can be performed safely. So safely for the crew, passengers and people on the ground.[34]"

- Fixing and detaching the pod to the aircraft is also a moment that safety aspects regarding personnel can be endangered, because the weight of the pod including the radar system is 250 kg. Therefore to detach and fix the pod to the aircraft a lifting device is foreseen. FMECA entry is 17.

- While performing maintenance while the radar is switched on and people walking around, it is possible that somebody is irradiated. The radiation can be harmful for people. FMECA entry is 05 and hazard code is CB.

Ad 2. Loss of system, or extensive damage of system

- When mounting points break and the pod falls down, then the radar system will be not repairable any more or severely damaged. Also see the hazard codes AA and AF in the hazard checklist in appendix E.3.1. FMECA entry is 17.

- When the cooling system fails and the radar does not switch to the safe mode = off, the pod and units in the radar system can be severely damaged, because of overheating. The pod contains an internal temperature control to prevent the radar system to become to cold or to warm. The cooling system also contains a temperature sensor. So no extra sensor is needed. FMECA entry is 18 and hazard code is EA and FG.

- When the pod leaks, the humidity of the air inside the pod gradually increases, so the units in the pod degrade, because of corrosion and oxidation, a lot faster as a result of the humidity and the temperature in Indonesia. FMECA entry is 16 and hazard code is FF.

Ad 3. Long term environmental effects.
No long term environmental effects possible.

Furthermore a hazard analysis is done with the help of a hazard checklist. The Hazard Analysis identifies which hazards (e.g. energy sources like pressure or sharpness or kinetic energy) are present in the operations and the hazard checklist is shown in appendix E.3.1.

7.4.1 Conclusion

Safety should be looked at during the design and the operation of MARS. But MARS is not a safety critical system. Anyhow the above aspects should be reconsidered, when re-engineering MARS and extra safety measures can be taken. An extra safety measure could be that the radar can only be activated after a double check is taken during maintenance.

8 Maintenance concept

This chapter describes the maintenance concept, which is developed. In the first paragraph is described how a maintenance concept is developed. In the second paragraph an introduction to the maintenance concept is given. The following paragraphs describe what the corrective- and preventive maintenance includes for the MARS flight segment. The fifth paragraph describes what support is needed for the maintenance. In the last paragraph the maintenance costs are described.

8.1 How to develop a maintenance concept?

In this chapter the development of the maintenance concept for the flight segment of the MARS system is described. The maintenance concept is developed on subsystem level. To develop a maintenance concept according to the methods described in paragraph 3.3, the repair times and costs of units are needed. Information about costs and repair times are not available, so it was not possible to develop a maintenance concept with the most cost and time effective maintenance rules. The assignment to develop a maintenance concept cannot be finished like it was planned at the beginning of the project. In Appendix F.1 is illustrated how a maintenance concept is developed and what the required information is to determine the most effective maintenance rules.

The development of a maintenance concept can be divided in four different parts. The four parts are illustrated in appendix F.1 and described as follows:

1. The development of the maintenance concept starts with the identification of the consumer needs and the definition of system operational requirements. For MARS no requirements were given so a mission profile is set up and described in chapter 6. Requirements with regard to RAMS are described in chapter 7.

2. The next step is the FMECA, which identifies the maintenance critical items. For a more elaborate explanation, see §3.1.3 and §7.3.1.1. The FMECA is included in appendix E.2.2. The RAMS analysis also contributes to the maintenance concept because it identifies critical units and subsystems regarding reliability, availability, maintainability and safety in the MARS system.

3. The maintenance identification must be done to determine the required maintenance tasks and maintenance policy that will support the consumer needs and the operational requirements. See also appendix E.2.3 and F.2.

4. The last step is to make the maintenance concept operational, which implies the determination of spare parts, tools, equipment, training, skills, maintenance tasks, test procedures and facilities that will support the maintenance concept an the customer requirements.

The next paragraph describes the results, which are derived from the execution of these four parts in this graduation project.

Ad 1. The maintenance concept, which is developed for MARS is not complete. No system- and consumer requirements were available. The MARS project was cancelled during my graduation project, which implied that the information I acquired is limited.

Ad 2. As a result of the FMECA, no critical maintenance items were found. The FMECA divided the flight segment in electronic and mechanical parts, which require different kind of maintenance, see §7.2. The RAMS analysis makes clear what the required, obtained and allocated reliability is, what the necessary availability of the system is and the safety effects, which all influence the maintenance concept.

Ad 3. Maintenance actions are divided in corrective maintenance for electronic systems and preventive maintenance for the mechanical systems. No further specification can be given based on the analyses. The maintenance concept is corresponds with the formulated mission profile.

Ad 4. It was not possible to determine what support is necessary to make the maintenance concept operational. The subcontractors of Fokker Space must specify the necessary support for the systems they deliver to complete the maintenance concept, see §8.5.

In the next paragraphs is described what is developed as a maintenance concept for MARS. Described is what the preventive- and corrective maintenance tasks include, and what operational support is needed for the maintenance concept.

8.2 Introduction to maintenance concept

For the development of the maintenance concept a FMECA, appendix E.2.2, has been made to analyse MARS and to identify the maintenance critical items. The purpose of a FMECA is explained in paragraph 3.1.3 and 7.3.2. No maintenance critical items were discovered in the FMECA. The safety consequences of maintenance are covered in the safety analyses, see §7.4.

Furthermore a maintenance identification, see paragraph 7.3.1.2 and appendix E.2.3, has been done to identify the aspects like: which type of maintenance is needed (preventive or corrective), is the failure detectable and should the action be repair or replace. To decide what kind of maintenance policy is required for the unit a decision diagram is used. The consideration of costs could not be included. So, I looked at the failure consequence and the required availability of the system to decide what kind of maintenance policy is required, also corresponding with the formulated mission profile.

In appendix F.2, a decision diagram is included to show how to decide which kind of maintenance is preferred for the different systems and units. The type of maintenance a unit requires is a very important aspect, because of costs, availability and safety consequences. The results are included in the maintenance identification table. All the units of the radar will require corrective maintenance. Furthermore preventive maintenance for electronic systems is impossible, see § 7.3.

To initiate and do maintenance, support and facilities are necessary. The maintenance support consists of different things like tools, test procedures, personnel, spare parts etc., see appendix F.1.

The maintenance concept is founded on the results of the RAMS analyses, as described in chapter 7. The maintenance concept is divided in two parts, see paragraph 7.3 and 7.3.2 for more elaborate explanation, namely:

1. Corrective maintenance for electronic systems of the flight segment;

2. Preventive maintenance for the housing of the radar system.

In paragraph 8.3 and 8.4, the corrective- and the preventive maintenance for the MARS flight segment is described.

A maintenance flowchart is made to illustrate what activities should be done and what decisions have to be made when a failure occurs. The figure also shows what information is needed for the different failures or maintenance tasks. In appendix F.3, the maintenance flowchart is included. More elaborate description of the maintenance support can be found in §8.5.

8.3 Corrective maintenance

In this paragraph it is described what the corrective maintenance implies for the different subsystems. In appendix F.2 is demonstrated why corrective maintenance is the most effective maintenance policy for the radar system and other electronic systems. The reliability of the radar system is high (see § 7.1), so corrective maintenance will be sufficient for MARS. The required availability is low (see § 7.2), 16,5% f the total operational time. Therefore corrective maintenance is allowed.

8.3.1 Radar system

The radar system consists of different units. The units are all electronic units and are built up of different components. The units are designed and manufactured by TNO for the PHARUS system. Corrective maintenance is preferred for these units, because the failures occur random, for more elaborate explanation read § 3.1.1. If one of the units fails, except the T/R modules, (read § 7.1.2 for more information about T/R modules), it is immediately a serious failure, which implies that the mission (flight) is lost. Corrective maintenance should then be executed to get the system back into the available state.

Corrective maintenance for the radar systems approximately implies the following, see also the flowchart in appendix F.3:

If a failure occurs, the radar must be detached from the aircraft and transported to the workshop or laboratory. The radar can be repaired in the laboratory. The failure must be detected and the failed unit must be repaired. The repair will usually imply a replacement of a defect component. If it is not possible to repair a unit in Indonesia then the unit must be transported to the Netherlands.

The subcontractors of the MARS system must deliver the maintenance rules and failure detection methods for the units.

8.3.2 Rest of flight segment

The rest of the flight segment is built up out of COTS products. The COTS products allow corrective maintenance.

The advantages and disadvantages of COTS products in relation to maintenance are described below.

<u>Advantages of COTS products:</u>
COTS products are consumer products. COTS products are therefore easily and rather quickly available compared to products which are specially made. Furthermore COTS products are cheaper and have short order times.

Disadvantages of COTS products:
COTS products are fast changing because they are consumer goods. The following aspects are important for COTS products:

- It is often unknown how long the products will be available. If it is known that certain components or subsystem will not be available anymore in the near future then extra spares should be ordered. Otherwise the replacement by different but equivalent components or subsystems requires re-engineering of the MARS system.

- If COTS products, which are used in MARS, will change in the near future, then will these changes have impact on the design? An equivalent component will replace the former. The replacement of components within the different units implies re-engineering and not a design change. Re-engineering is defined as to make the necessary adjustments to components or systems so the component or system fits again in the functional design.

8.3.3 On-ground data preparation system

The on ground data preparation system is part of the flight segment, see paragraph 4.3.1 and exists merely out of computers. The stored data will be pre-processed, and will be transferred from the harddisks to long storage devices. A more elaborate description can be read in paragraph 4.3.1. The system must be placed in an air-conditioned room, otherwise the tapes will melt and stick together because of the humidity. An air-conditioned room is also preferable because the hardware will degrade faster because of the humidity.

The main purpose of the on-ground data preparation system is the conversion of the raw data from harddisks to tapes. When the data of the harddisks can not be converted to the tapes then the flight schedule will be delayed. A redundant set of harddisks is very useful in this case. Furthermore, with a redundant set of harddisks, it is always possible to immediately make or plan a second flight. This can be necessary in case of emergencies like forest fires or other calamities. Another advantage is that, if a harddisk fails, a redundant harddisk is available immediately. So a redundant harddisk must be carried in the aircraft during a campaign flight. In this way the failing of a harddisk is not a single point failure anymore.

A redundant set of tapes is also preferable, because if one set fails or causes delays, another set can be used for the data conversion. Indonesia has to determine whether they prefer a redundant set of harddisks and tapes. It is also possible to order a new set if a harddisk or tape fails. Tapes and harddisks are relatively inexpensive compared to the systems. So the purchasing of redundant harddisks and tapes is preferable but not required for the operating of the MARS system.

8.4 Preventive maintenance

Preventive maintenance for the housing of the radar is needed. The pod consists of mechanical systems. Mechanical systems require a different maintenance treatment than electronic systems. For the pod preventive maintenance is possible. In the next paragraph is described what the pod includes and what actions have to be initiated to maintain the housing of the radar. Appendix F.2 illustrates how is determined that preventive maintenance is necessary for the pod. The information in the next paragraphs is derived from TNO-FEL, and describes what maintenance actions they periodically perform on PHARUS.

8.4.1 Housing of radar system

The Radar system is housed in a pod and mounted under an aircraft.

POD

The pod is the housing of the radar system. The pod contains the following parts:
1. Pod and radome, which is the housing of the radar;
2. Rubber seals and O-rings to close the pod;
3. A base plate on which all the units are mounted;
4. A cooling system, which takes care of the temperature control;
5. Motor of the cooling system;
6. Expansion tank for the cooling system.

8.4.2 Scheduled maintenance

The pod must be maintained periodically. The scheduled maintenance will consist of small maintenance services and big maintenance services. The time between the overhauls is estimated according to when TNO approximately had the scheduled maintenance services, which they perform on PHARUS. The time and actions described are not derived from the analyses or from the methods to develop a maintenance concept, but are derived from the interviews held within TNO-FEL.

Small maintenance should be done twice a campaign, or approximately every 75 operating hours (10 flights). The overhaul, as done by TNO for PHARUS includes the following actions:

1. Visual check-up's of radar system, pod and cooling system;
2. Fill up of the cooling fluid with fluorinert, and bring back to specified pressure;

Heavy maintenance overhaul should be done once a year, or approximately every 300 operating hours (40 flights). The overhaul, as done by TNO for PHARUS includes the following actions:

1. Visual check-up's of radar system, pod, cooling system;
2. Refill of the cooling fluid, fluorinert;
3. Replacement and repair of the defect T/R modules;
4. Check whether the radar functions in the right way, check all the different modes;
5. Check with an spectrum analyser if all the units still work within their specifications;
6. Check the logbook, where all the failures and incidents the occurred are registered;
7. Replace the expansion tank and check if the cooling motor is not corroded yet;
8. Check all the rubbers in the pod, and replace if necessary;
9. Clean the pod, rubbers and bolts if necessary and grease the cover of the pod;
10. Check all the bolts in the pod, and replace if necessary;
11. Check the antenna pattern and line up if necessary;
12. Check the mounting points with the aid of dye-penetrant on hairline cracks.

The time between the overhauls is probably estimated too short. When the MARS system is used, the interval periods must be adapted according to the use of MARS. For example, it is not possible to estimate how fast the rubber seals in the pod will degrade in Indonesia, because the temperature and humidity is different. So with the aid of visual inspections the degradation must be determined. The perishing time of the rubber seals must be recorded and the scheduled maintenance actions must be amended accordingly.

8.5 Support for maintenance

Appendix F.1 illustrates that operational support is needed for a maintenance concept. The subcontractors must specify the necessary support. In this paragraph is described what support is needed to do the maintenance. The support covers when, how, by whom, with which means and where, maintenance must be performed on the flight segment. The flowchart in appendix F.3 illustrates what information must be available and what decisions have to be taken to execute the maintenance actions. In the flowchart the when, how, who, what and where are visible and described in the next paragraphs. In appendix E.2.3, maintenance identification, information in included for the maintenance support, but this information must be specified to component level.

8.5.1 When

The subcontractors should make clear when and how often the preventive maintenance and inspections must take place. The subcontractors must also determine when the electronic units must be inspected and calibrated, so the systems will work within specifications.

If a unit fails, it will take at least one day all together to replace a unit, regardless what unit must be replaced. To replace and repair units, the following activities should be initiated:

1. Detach radar from aircraft;
2. Open the radar;
3. Detach defect unit;
4. If repair, ship to reparation facility (in Indonesia and otherwise in the Netherlands);
5. Fix new/repaired unit on base plate;
6. Close radar;
7. Mount to aircraft;
8. System check.

If the action is repair then the time to transport to and from the reparation facility is the additional down time. If the unit has to be repaired in the Netherlands then the costs of repair will be substantially higher compared to the costs of repair in Indonesia.

8.5.2 How

The subcontractors of the MARS project should deliver maintenance policies for their sub systems. The following aspect should be included:

1. How a unit can be tested;
2. How to detect and locate a failure;
3. What test equipment and tools are needed;
4. Under what environment condition the testing has to take place;
5. What the taken steps should be to execute the test or the repairing.

In the following table an example is shown. The table is derived from an acceptance procedure for electronic systems developed by the company Aero-sensing, specialised in radar systems. This procedure describes tests for the radar systems, which they supply.

Unit	Chirp generator
Test	Functional test
Test equipment	Multi meter
	Oscilloscope
	Connector adapters
Environmental conditions	Room temperature: 25 °C
	Humidity: 20%-80%
	Altitude:
Execution rule	

Table 8-1 Failure detection, isolation and repair procedure

For all the units and subsystems these aspects should be made clear by the subcontractors. With this information a useful maintenance concept can be made, which can be used autonomously in Indonesia.

8.5.3 Who

BPPT should be able to do the maintenance of the MARS system. Training for MARS will contribute to their system knowledge of MARS and their maintenance knowledge. The training, which should be provided, is described in the following paragraph.

The following paragraph is derived from the MARS system definition [2]. The implementation of the training program will be realised as a "training on the job", during the MARS-1 commissioning period. The following training program is foreseen:

Operations Training:
- Mounting of MARS-1 system to aircraft;
- Pre-flight system check;
- MARS-1 flight operations;
- Data conversion;
- Data quality control;
- SAR processing;
- Thematic processing, comparing the digital images.

Maintenance Training:
- MARS-1 maintenance (Flight- and Ground Segment);
- preventive maintenance;
- diagnostics, (interpretations of signals and actions by operator);
- corrective maintenance (e.g. exchange of LRU's);

The following trainings should be added to the training program for the MARS flight segment:

1. Testing of units in RADAR;
2. Calibrating of units in RADAR and calibrating RADAR system;
3. Corrective maintenance, detection and isolation of failures and replacement of components;

The training program for Indonesia is then completed.

8.5.4 What

What in relation to maintenance implies what equipment and tools are needed in Indonesia to detect, isolate, locate and repair failures in units and to replace units? The subcontractors of Fokker Space must specify what the required tools and equipment is for MARS.

Failure detection, isolation and repair
This paragraph describes what equipment and tools are required to do the detection, isolation and location of failures in the flight segment. The data about the equipment is derived from TNO-FEL and Fokker Space.

The following test equipment is used by TNO to detect and locate approximately 80 % of the failures in the radar system:

1. Multi meter;
2. Oscilloscope.

An oscilloscope and a multi meter can locate 80 % of the failures within the radar. To do a more elaborate test, a spectrum or signal analyser is required. With this equipment at least another 15 % of the failures can be located. So for approximately 5 % other relatively expensive high frequency equipment is needed.

Connector-adapters are necessary to connect the units to the test equipment. The radar system always have to be detached from the aircraft and opened, which always takes a day in total together. All units can be repaired in a laboratory situation, also in Indonesia, assumed they have the right equipment in Indonesia. All components should be available or could be ordered.

On the campaign base the maximum maintenance action is to replace units or T/R modules. But repairing, which is replacement of a defect component is not possible.

The subcontractors of MARS must make clear whether the systems use a metric or an inch system and what tools are necessary for the systems. The required tools for Indonesia can then be determined. The repairing of parts must be done in a workshop or laboratory where they have the necessary equipment and tools.

Maintenance can not be done in the operational field, which is the campaign base. Only replacement of units can be done, but the radar will always have to be detached from the aircraft. Also the filling of cooling liquid, and filling of dry air can be done in the operational field.

8.5.5 Where

Almost all units of the radar system are shop replaceable units, which means that they have to be repaired in a laboratory or workshop environment. A laboratory is usually not available on the campaign base. This means that the failed units always have to be transported to a laboratory or workshop for repair. The T/R modules are the only line replaceable units in the radar system, which means they can be immediately replaced, by a new unit, on the campaign base.

The units that cannot be repaired in Indonesia are sent to the Netherlands. The transportation of the unit costs extra time and money. So preferred is to repair all the units in Indonesia. The flowchart in appendix F.3 includes the decision of doing the maintenance action in Indonesia or in the Netherlands.

8.6 Maintenance costs for MARS

No detailed information about costs of units could be acquired. Therefore it was not possible to develop the most cost effective maintenance tasks for the units and subsystems. Furthermore no prediction for spare parts can be made.

Maintenance costs for MARS do not involve all costs as described in §3.2.4 and appendix B.3. But MARS involves the following costs for initiating and executing maintenance:

- Labour;
- Equipment;
- Tools;
- Materials;
- Spare parts;
- Necessary transportation.

Read § 3.2.4 for a more elaborate description of maintenance costs. No indirect costs are involved from the standstill of the MARS system. Other costs because of failures during flight are described in the next paragraph.

The costs of one flight are approximately Dfl 25.000, - in the Netherlands. A lost flight is an enormous waste of money. Because the costs of a failed flight are very high, a pre-flight check should always be executed. So the investment in a flight will be lost when, during the flight a unit or subsystem fails. Therefore in consideration must be taken, what the costs are if a flight is cancelled compared to more investments in maintenance. The costs in Indonesia are of course different than here. That is because labour costs in the Netherlands are higher compared to Indonesia. A pre-flight check is a good prevention method to prevent the aircraft from taking off with a non-working radar.

8.7 Conclusion

This chapter describes the maintenance concept for MARS. The maintenance concept is not completed. The completion of the maintenance concept was not possible because the information was not sufficient to develop a complete maintenance concept. The maintenance concept must be more detailed by the subcontractors and suppliers for the different systems. Furthermore Fokker Space must check whether the maintenance concept gives sufficient information for Indonesia.

The maintenance concept is divided in preventive and corrective maintenance tasks for the different subsystems. Furthermore is described what kind of support is needed regarding to when, how, what, who and where the maintenance must be executed.

The maintenance of software is not part of this research. Nevertheless it is a very important part for the MARS system. Fokker space must pay close attention to this subject.

9 Conclusions and recommendations

In this chapter the conclusions and accompanying recommendations of this research are given. The conclusions are based on the RAMS analyses and the development of the maintenance concept of this graduation project. The conclusions and recommendations are divided in five different parts namely: reliability, maintenance, safety, MARS project and availability.

Reliability

[1] **Conclusion** (see § 2.3 and § 5.3)
For the PHARUS system the failures are not recorded in a database, because it was an experimental system. They did keep a logbook to register all failures and other happenings that occurred during the use of the PHARUS system.

Recommendation
When the MARS system is used in Indonesia, the occurring failures and repair information should be recorded. With this field data the system can be improved and weaknesses can be eliminated. Failure registration can also contribute to the reliability of MARS. From field data also a reliability prediction can be made. Then, when MARS has been in use for a longer time, the former predicted reliability can be compared to the calculated reliability from the field data, when it is used longer. In this way, other deficiencies can be removed from the MARS system, when the MARS upgrades are realised. Furthermore, the repair information can be used to specify the maintenance documentation.

[2] **Conclusion** (see § 4.3.1 and § 7.1.2)
The antenna exists of 48 T/R modules. The T/R modules are the most expensive and most important parts of the MARS system, and have the highest failure rate. An advantage is that MARS includes 48 modules, and that the overall system performance degrades gradually with the number of defective T/R modules. The failure of one T/R module does hardly have a direct effect on the resulting digital images. Only when five or more T/R modules fail it will be visible in the digital images. But when the reliability of one T/R module is 0.442, then the probability that five modules fail = $3.1 * 10^{-8}$ in 3300 operating hours. So that probability is very small. This implies that failing of a few T/R modules will not significantly affect the reliability of the MARS system.

Recommendation
Sufficient performance of the digital images can be reached when a flight is done with 43 out of 48 T/R modules. So, it is not necessary to replace every failed T/R module. The limit of failed T/R modules, for which the MARS system can still operate perfectly, is estimated at 10 %, which means a maximum failing of approximately 5 T/R modules. But the probability is very small, even negligible that 5 T/R modules fail. This can be an advantage when the system is in the middle of a campaign and maintenance is planned in for example 4 months. In this way maintenance actions can be clustered and the downtime because of maintenance can be reduced.

[3] **Conclusion** (see appendix E.1.2 and E.2.2)
The flight assembly of MARS is a single non-redundant chain of units and subsystems, almost each unit and subsystem in the flight assembly forms a SPF (Single Point Failure). The SPF's in the radar system are caused by: the Chirp generator; Frequency

generator; Up converter; Splitter; Power supply; Data Acquisition System; Data Storage System, Control system, IF Amplifier, Timing Generator, Radar Control, Cooling System, Club 1, Down converter Horizontal (H); and Vertical (V); Combiner H and V and Output Buffer H and V. SPF means that one single failure of a unit can lead to a total failure of the system, instead of a degraded mode.

Recommendation
The MARS system includes a lot of Single Point Failures. But the radar system fails with a probability =0.00036 per flight (5 hours), which implies that 1 out of 2778 flights fail because of the failing of the radar. So no extra reliability measures have to be taken to get a better reliability.

If a better reliability is needed then the implementation of redundant units or subsystems can be taken in consideration. Another possibility is to deliver spare parts with the MARS system. Costs of a double version versus the downtime caused by failure of the subsystem could be weighed against each other. For the weighting of costs against the downtime, the importance of the two factors should be taken in consideration.

[4] **Conclusion** (see appendix E.1.4)
The following failures lead to serious failures, which means a loss of mission or loss of one flight, (see appendix B), and fail with the highest fail probability;

- Chirp generator;
- Frequency generator;
- Cluster control.

Recommendation
These three units have the highest failure probability within the radar system. The costs of supplying extra spare parts for these units should be weighed against the advantages like the lower repair time of these units. If shipment to the Netherlands is necessary then the costs are even higher. Also read the recommendation of conclusion 3.

[5] **Conclusion** (see § 7.1.2 and appendix E.1.5)
A reliability prediction is made for the radar system with the aid of the military handbook of electronic equipment [14]. For the other subsystems of the flight segment reliability information is not available. Therefore a reliability prediction is made of the other subsystems by calculating from the relation between the complexity and the reliability of the radar system. The reliability of these subsystems is proportionately to the reliability of the Radar system. The multiplication of the reliabilities of the different subsystems computes the total reliability of the flight segment.

Recommendation
When MARS is developed and the subsystems for the flight segment are purchased, Fokker Space should consider what reliability they require from their subcontractors. The reliability of the subsystems together determines the total reliability.

[6] **Conclusion** (see appendix E.1.2 and E.2.2)
MARS has no redundancy because of the horizontal and vertical polarisation of the antenna. In the first place the down converter, combiner and output buffer seem to be implemented redundant, because of the H and V units. But the system can then only be used for either horizontal or vertical polarisation. So a failure of one of the units causes a degraded mode, but not a critical failure. MARS can still be used in the degraded mode for other applications. The application for MARS, as assumed for this research,

is forest monitoring. For forest monitoring H and V polarisation is necessary. So a possibility exists that it could be used as a redundant system.

Recommendation
If the data recording is only H or V polarised, which implies single polarisation then the resulting digital images are only two-coloured. Depending of the mission of the flight, single or dual polarisation is required or recommendable. For forest monitoring dual polarisation is necessary. But it is possible that for coastal monitoring, or forest fires monitoring, the radar system can still be used. So if the H or V polarisation is broken, the MARS system can still be used for other applications than forest monitoring.

<u>Maintenance</u>

[7] **Conclusion** (see chapter 8)
The maintenance concept could not be completed because not all the required data was available.

Recommendation
To develop a maintenance concept, data and information about costs and repair times of the subsystems and units must be available. Otherwise it is not possible to determine what the most time- and cost effective maintenance rules must be for the different units.

[8] **Conclusion** (see § 2.3)
For MARS, a maintenance concept is delivered. This concept is developed during the re-engineering phase. So the MARS system is not used yet. The use of MARS will probably be different than expected during the re-engineering phase.

Recommendation
During the operational phase of MARS, the maintenance concept should be revised and adjusted to the operational application and experiences during the operational lifetime of MARS. So the failures of units and subsystems should be recorded. If some failures occurs extremely often, like every 5 flights, or occur more often compared to other failures then a preventive maintenance guideline can be made to prevent the failure. Also the corrective maintenance guidelines must be revised and supplemented, according to the failure and what was necessary to repair the failure. The registration of the failure and the repair methods are useful for future personnel.

[9] **Conclusion** (see § 8.5.4 and appendix F.1)
To use the maintenance concept, certain tools and equipment are required in Indonesia to do the repairs.

Recommendation
It is advisable for Indonesia to purchase all the tools and equipment, which are recommended by the subcontractors. If they have all the tools and equipment, then BPPT can do all the repairs and replacements themselves. Assumed is that the personnel of BPPT is skilled enough to do the repairing. In this way BPPT will learn the most of the RADAR and the high frequency technology.

[10] **Conclusion** (see appendix F.2)
It is not possible to do preventive maintenance for the electronic systems. In order to ensure that the units operate within specifications, it must be possible to calibrate the

units. The calibration of the units is considered as a functional test and not as preventive maintenance.

Recommendation
A so-called SYSCAL (system calibration) measurement, which detects and corrects, drift-related declinations could be built into the MARS system. The investment and re-engineering costs that are necessary for this implementation should be weighed against the advantages. PHARUS does not use a SYSCAL system. It is also possible to calibrate the systems during a planned maintenance action. This will cost less money, because no SYSCAL system has to be implemented. But it is less accurate, because the units are not continually checked and calibrated.

Safety

[11] **Conclusion** (see § 7.4 and appendix E.2.2)
It is possible that the radar signal can harm people because of its radiation. When the RADAR is in the air then it is not harmful to the crew, because MARS radiates away (to the side) from the aircraft. But when performing maintenance on the MARS system, then the radiation can be harmful if somebody is close to the RADAR and if the system radiates on full power.

Recommendation
If MARS is actively transmitting during maintenance, then a safety control, which indicates that the RADAR is active transmitting, is necessary. It is even better to implement a sensor, which switches on an alarm of noise or lights when somebody stands in front of the active sending part of the RADAR system within a radius of approximately 5 meter. The subcontractor must specify the required safety distance for the radar system. Another possibility is to put the radar system in a bin with radiation absorbing material.

[12] **Conclusion** (see § 7.4 and appendix E.2.2)
The pod has a weight of 250 kg. The mounting points between pod and aircraft can break. If it falls down when it is in operation, it is catastrophic. The pod could injure or kill a person or damage an object, and probably be severely damaged itself. The safety of the pod is inspected by the RLD.

Recommendation
Fokker Space must check whether the mounting points are also strong enough for the weather conditions in Indonesia. The RLD can assure the safety of the mounting points.

[13] **Conclusion** (see § 7.4 and appendix E.2.2)
The leaking of the pod can lead to serious failures. The radome of the pod is a little bit porous. So the humidity of the air inside the pod gradually increases. The units degrade a lot faster because of corrosion and oxidation as a result of the humidity and the temperature in Indonesia.

Recommendation
After every flight, the pod must be flushed with dry air. In this way all the units are dry again, and the chance of corrosion is smaller. Before the flight takes of, create an over pressure of dry air. In this way the humidity of the air in the pod does not increase too quickly.

MARS project

[14] **Conclusion** (see § 2.2, § 2.7 and § 6.1)
The customer, BPPT in Indonesia, did not make clear what the requirements for the MARS system and the maintenance concept are. Furthermore they did not specify what their capabilities are. It is not made clear what the knowledge in Indonesia is of remote sensing systems, RADAR systems and high frequency technology. As a result of this, BPPT will probably not be able to work accurately with the MARS system and learn optimal from the system. But for this graduation project is assumed is that their capabilities are sufficient.

Recommendation
The maintenance concept should be tuned with the desires of the customer. The capabilities and skills of BPPT in Indonesia should also be tuned with the maintenance concept. BPPT must make clear what the capabilities and skills of the BPPT's personnel and laboratory or workshop in Indonesia are. The specification of the maintenance concept and maintenance training can then be better tuned with the needs of BPPT.

[15] **Conclusion** (see chapter 8)
The subcontractors of Fokker Space should provide maintenance guidelines for the MARS subsystems they supply. In this way Fokker does not have to develop and specify the maintenance guidelines themselves.

Recommendation
Fokker Space must check with the subcontractors that they deliver maintenance guidelines for the subsystems and units they deliver. The subcontractors of Fokker Space should prepare the maintenance guidelines for BPPT in Indonesia. Fokker Space must check that these maintenance guidelines are sufficient for BPPT, so BPPT is able to do the repairing and maintenance autonomously.

[16] **Conclusion** (see § 2.2)
The MARS project is meant to be a learning project for BPPT in Indonesia. The maintenance concept should be tuned with the desires of the customer. Another deliverable of the MARS system is the training they provide when they deliver the system to Indonesia. The training program covers training for the operational use and for maintenance actions.

Recommendation
The training program, which will be provided by Fokker, must be tuned with the capabilities of a laboratory or workshop in Indonesia and the skills of BPPT's personnel in Indonesia. The maintenance training consists of an operations training and a maintenance training. The specification of the maintenance concept and maintenance training can then be fitted better to the needs of and desires of BPPT.

[17] **Conclusion**
The MARS project has been temporarily stopped because of the turbulent and unstable political situation in East-Timor and Indonesia. The technology that is used in PHARUS is ageing, because new technologies and new remote sensing systems are being developed.

Recommendation
When the peace returns in Indonesia again, this project might be continued again. Maybe new systems and technologies have been developed, which have the same

performance and can also function as a learning project for BPPT. Fokker Space must pay close attention when continuing the project again, and maybe change to another but similar remote sensing system.

Availability

[18] **Conclusion** (see § 7.2)
The use of the flight assembly of MARS is calculated to be 16.5 % of the 2000 working hours a year. This is the time that the flight assembly should be available.

Recommendation
This implies that 83.5 % of the time remains to convert and process the raw data. The remaining time for maintenance of the flight segment is also 83.5 % of the time, because these actions can be executed simultaneously. It is predicted that less than 2 flights a year will fail, see § 7.1.4. So the rest of the time is left to do maintenance, without endangering the availability of the MARS system.

[19] **Conclusion** (see § 4.3.1 and § 8.3.3)
When the data of the harddisks can not be converted, in the on ground data preparation system, to the tapes then the flight schedule will be delayed.

Recommendation
A redundant set of harddisks is very useful in this case. Furthermore, with a redundant set of harddisks, it is always possible to do immediately a second flight if necessary, in case of emergencies like forest fires or other calamities.

[20] **Conclusion** (see § 4.3.2)
The Ground subsystems, in relation with the maintenance concept, are not so important because the failure of the subsystems of the ground system, cause merely a delay, but the flight schedule will not be affected, as opposed to the failures of the flight segment.

Recommendation
What is important of the ground system is the maintenance of the used software. The managing of the version control, when future upgrades are installed should be controlled. Software upgrades should be registered, so it can be retrieved what has been changed in the period between two upgrades of MARS.

List of abbreviations

ADC	Analog to Digital Converter
BIT	Built In Test
BPPT	Bandan Pengkajian dan Penerapan Teknologi
	Indonesian Agency for the Assessment and Application of Technology
COTS	Commercial Of The Shelf
CluB	Cluster control (Besturing)
DAS	Data Acquisition System
DPS	Data Processing System
DSS	Data Storage System
FBD	Functional Block Diagram
FMECA	Failure Modes, Effects and Criticality Analysis
GPS	General Positioning System
H	Horizontal
HW	Hardware
IMU	Inertial Measurement Unit
KIM	Koninklijk Instituut voor de Marine (Royal Institute for the Navy)
LRU	Line Replaceable Unit
MARS	Multi-purpose Airborne Radar System
MIL-HNDBK	Military Handbook
MSG	Maintenance Steering Group
MDT	Mean Down Time
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
MTTM	Mean Time To Maintenance
MTTR	Mean Time To Repair
NLR	National Aerospace Laboratory
OPS	Operations
PHARUS	PHased ARray Universal SAR
RAC	Reliability Analysis Centre
RADAR	RAdio Detection And Ranging
RAMS	Reliability, Availability, Maintainability and Safety
RAT	Redundant Array of Tapes
RBD	Reliability Block Diagram
RCM	Reliability Centered Maintenance

RLD	Dutch Civil Aviation Authority
SAR	Synthetic Aperture Radar
SRU	Shop Replaceable Unit
SPF	Single Point Failure
SW	Software
SYSCAL	SYStem CALibration
TNO-FEL	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek- Fysisch en Elektronisch Laboratorium (Dutch organisation for applied physical research - Physics and electronics laboratory)
T/R	Transmit / Receive
TUD	Delft University of Technology
TUE	Eindhoven University of Technology
V	Vertical

List of definitions

Availability	The probability that a system is in its intended functional condition at a given time and therefore is either in use or capable of being used in a stated environment.
Corrective maintenance	The actions performed, as a result of failure, to restore an item to a specified condition.
COTS	Consumer goods, hardware and software, which are available everywhere and relatively cheap.
Critical failure	A failure involving a loss of function or secondary damage that could have a direct adverse effect on operating safety.
LRU	Line replaceable unit means that a unit should be totally replaceable.
Maintainability	A measure of the ease and rapidity with which a system or equipment can be restored to an operational condition.
Maintenance	All actions necessary for retaining an system in a specified condition before failure or breakdown (preventive maintenance) or the process of restoring an item to return it to a workable condition (corrective maintenance).
Maintenance concept	A maintenance concept is defined as the collection of rules regarding when, how, by whom, and with which means, maintenance must be performed on the technical system.
Maintenance identification	Per item investigate which type of maintenance it will require: is the failure detectable, should the action be repair or replace, is it a long lead item, does it need preventive or corrective maintenance etc.
Preventive maintenance	The care and servicing by personnel for the purpose of maintaining system safety and reliability levels through systematic inspection, detection, lubrication, cleaning, etc. Preventive maintenance includes scheduled maintenance.
RCM	A disciplined logic or methodology used to identify preventive maintenance tasks to realise the inherent reliability of equipment at a maximum expenditure of resources.
Redundancy	The design practice of replicating the sources of a function so that the function remains available after the failure of one or more items.
Re-engineering	To make the necessary adjustments to components or systems so the component or system fits again in the functional design.
Reliability	The characteristic of a system expressed by the probability that it will perform a required function under a stated condition for a stated period of time.
Scheduled maintenance	Periodic prescribed inspection and servicing of units accomplished on a calendar, mileage or hours of operation basis.
SRU	Shop replaceable unit means that the unit must be repaired in a laboratory.

Subsystem	The subsystem referred to are the white blocks as shown in figure 2.1
System	The system in this research refers to the MARS system.
Unit	Units in this research are the separate parts from which the subsystems are assembled. The units are visible in the figures in appendix C.
Unscheduled maintenance	Those unpredictable maintenance requirements that had not been previously planned or programmed but which require prompt attention and must be added to, integrated with, or substituted for previously scheduled workloads.

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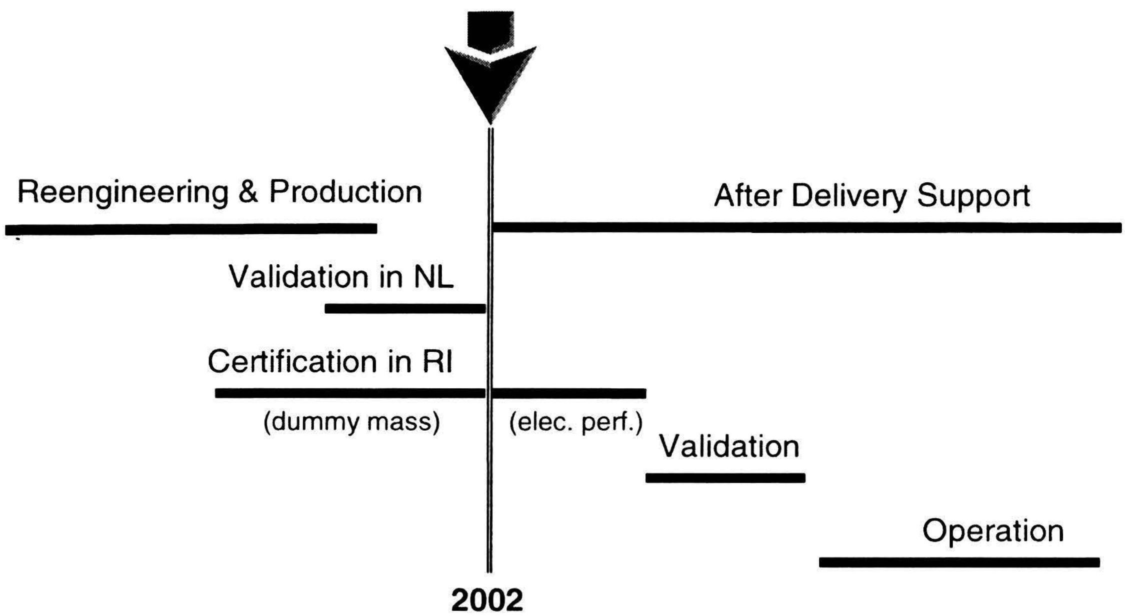
Appendices

Appendix A Research description

A.1 MARS time table



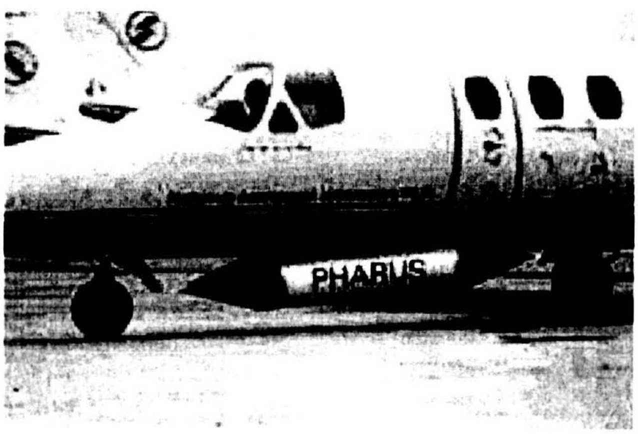
A.2 Methods for RAMS analyses

Analysis/ Tool	Mission/ objective of analysis
Reliability	
Functional Block Diagram	The FBD is very useful to make the unit- and component interfaces (electrical, structural, mechanical, thermal, other), data- and command flows visible.
Reliability Block Diagram	The RBD is different from the FBD in the sense that the RBD does not focus on the design aspects, but makes visible how much functionality remains after one or more failures.
Reliability prediction	Reliability Prediction: the reliability prediction is made to prove by bottom-up calculation that the (sub-)system reliability requirement is met.
FMECA	The Failure Modes, Effects and Criticality Analysis starts by identifying the functions (in requirements phase) or components (when design is available). Subsequently the safety- and reliability effects and propagation of the failure to higher levels are determined. As last part, the criticality (severity, probability) of each failure is determined.

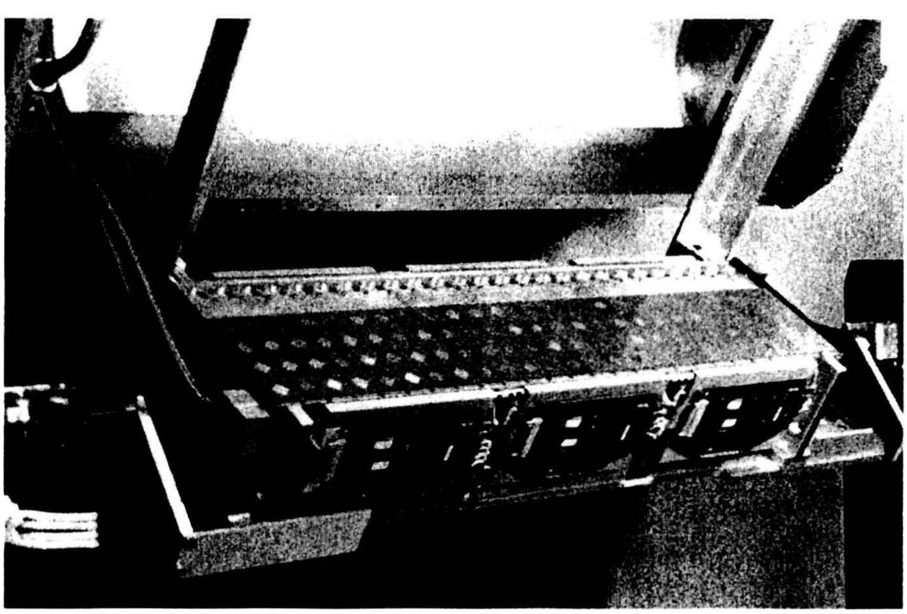
Fault Tree Analysis	Top-down failure analysis, which investigates the presence of common- mode failures, the presence of sufficient failure tolerance. FTA can be performed qualitatively and / or quantitatively.
Maintainability	
Maintainability Prediction, hardware	For hardware the prediction consists of determining the average and maximum duration of each of the maintenance actions (including e.g. logistical activity).
Maintenance Identification	Maintenance Identification: per item investigate which type of maintenance it will require: is the failure detectable, should the action be repair or replace, is it a long lead item, does it need preventive or corrective maintenance, etceteras.
Scheduled Maintenance Analysis	Determination of the optimal maintenance-, inspection intervals (including whether the inspection interval should be smaller at end-of-life). Also is the interval time- or wear-out dependent (mileage, switching / mating cycles), or should the maintenance be opportunistic.
Unscheduled Maintenance Analysis	Using FMECA, FTA and reliability prediction (MTBF), determine search-pinpointing procedure for each failure type, and the relevant refurbishment/ repair/ replace/ reverification tasks.
Spares Requirements Analysis	As a function of the MTBF and the MTTR determine the needed number of spare parts, and determine the location where they need to be stored.
Availability	
Availability analysis	Predict the product availability from the failure- and repair data. Useful for the operational phase of a system.
Safety	
Design Hazard Analysis	Identifies which hazards (e.g. energy sources like pressure or sharpness or kinetic energy) are present in the design. A must in the definition and verification of safety prevention and control, i.e. all lifetime phases.
Operations Hazard Analysis	Identifies which hazards (e.g. energy sources like pressure or sharpness or kinetic energy) are present in the operations. For not too complex systems it has much overlap with the design hazard analysis and the added value could be small. A solution is to include this information in the DHA.

Appendix B Theoretical scope

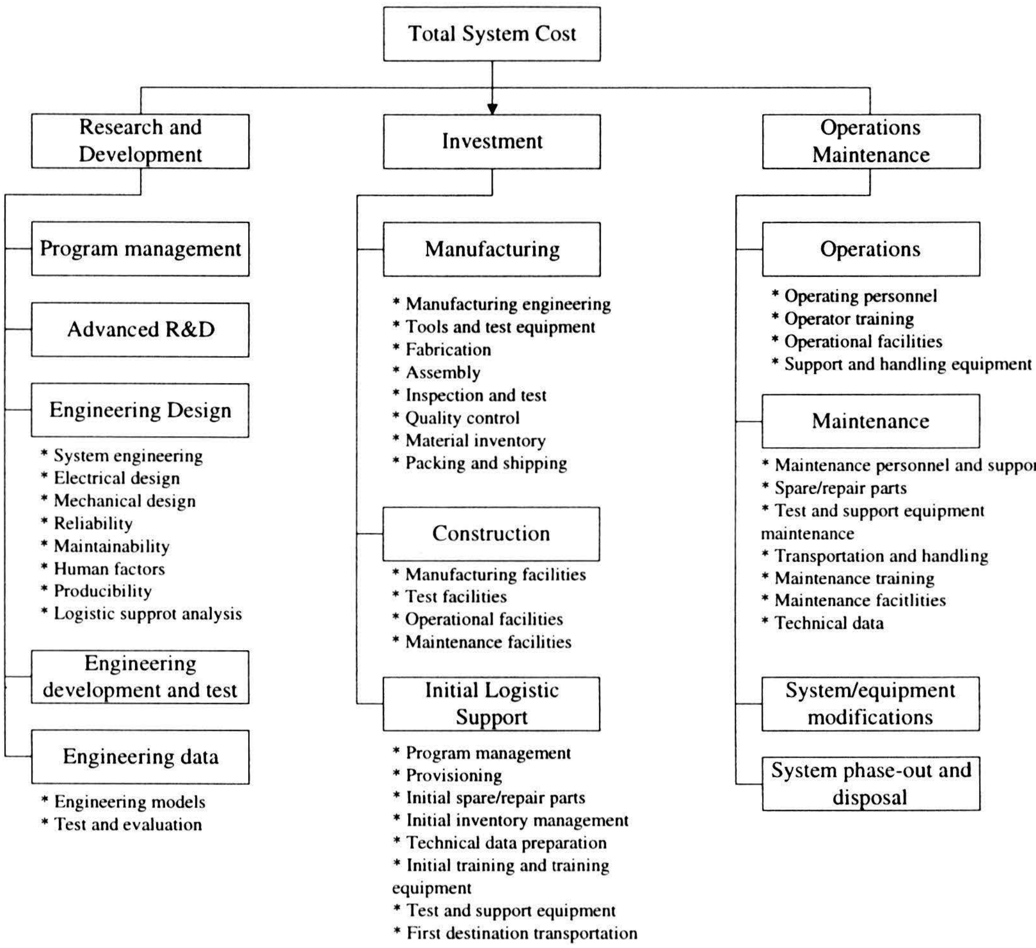
B.1 PHARUS under aircraft



B.2 Inside of PHARUS

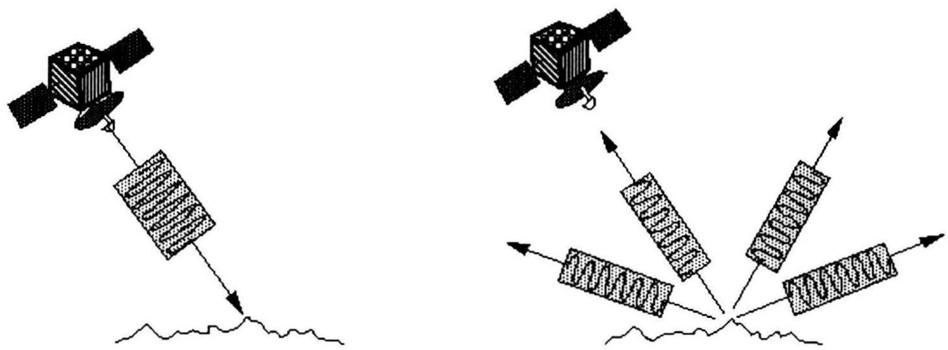


B.3 Cost Breakdown Structure

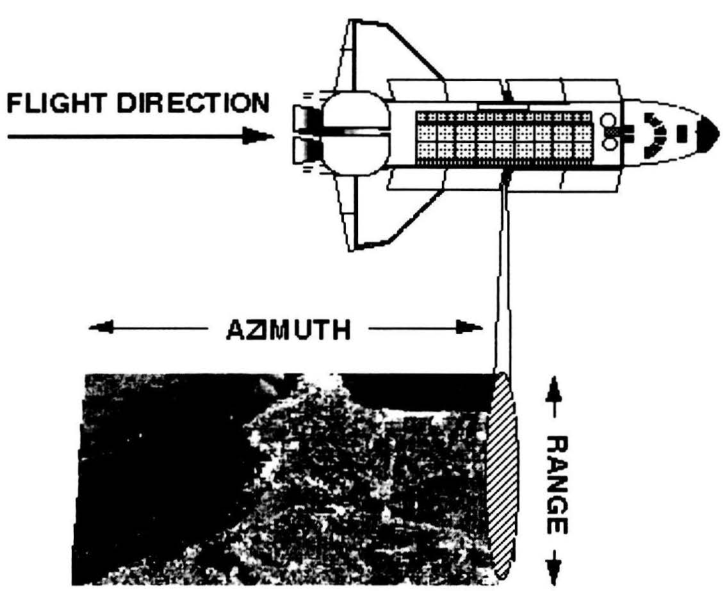


B.4 Radar illustrations

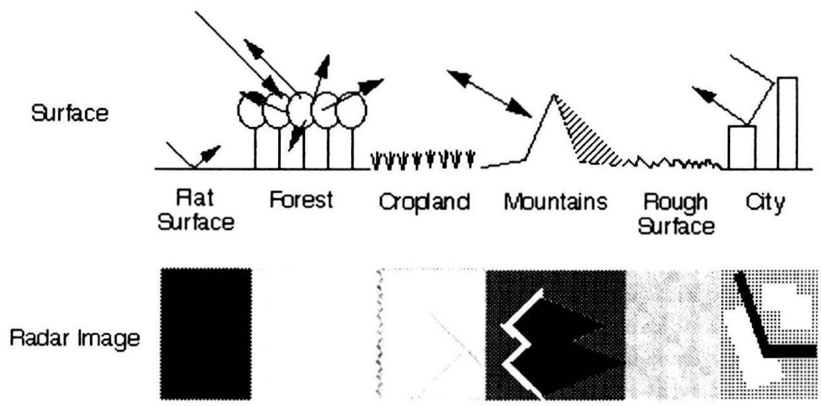
B.4.1 Radar transmits a pulse and measures the reflected echo (backscatter).



B.4.2 Building up a radar image using the motion of the platform

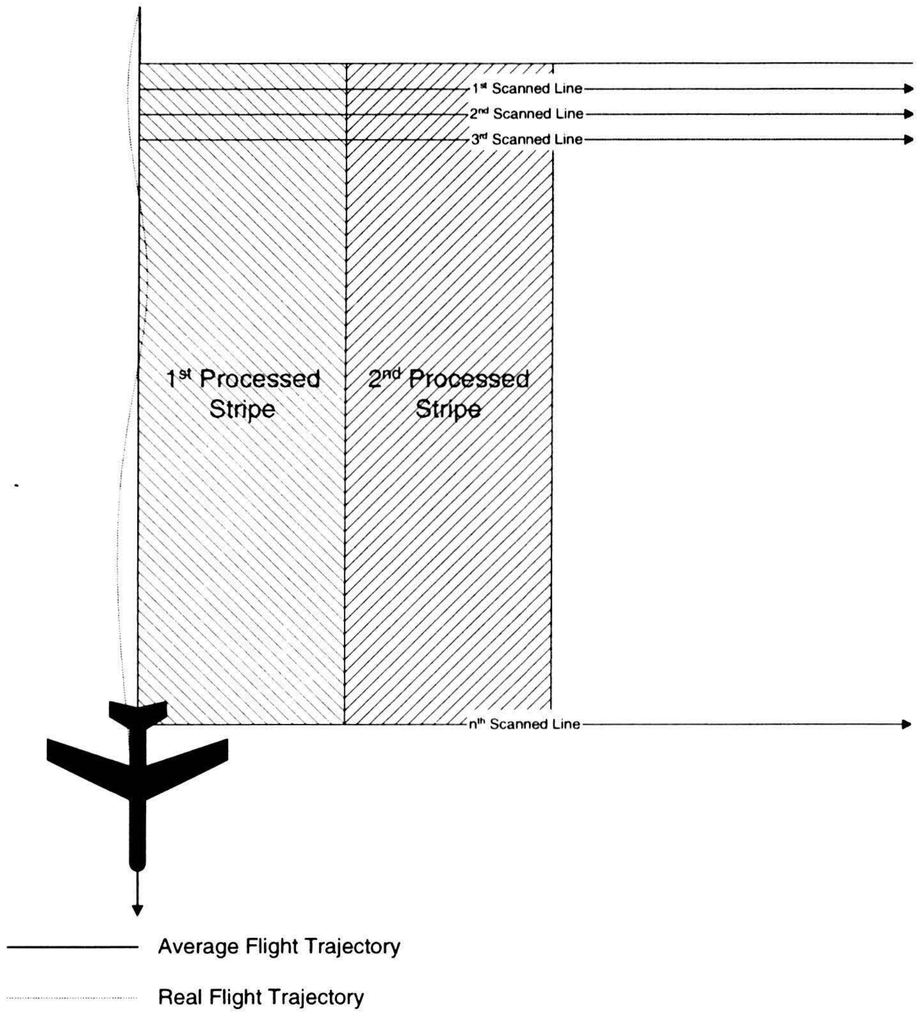


B.4.3 Imaging different types of surface with radar.



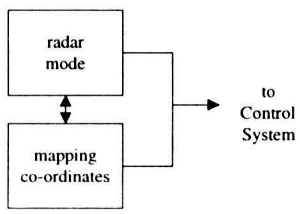
B.4.4 PHARUS image of Amsterdam airport Schiphol

B.4.5 Data acquisition and processing geometry

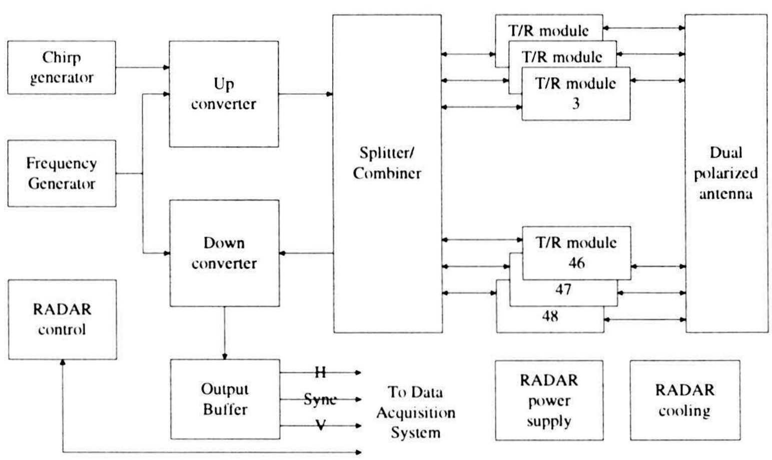


Appendix C Block diagrams of subsystems of MARS

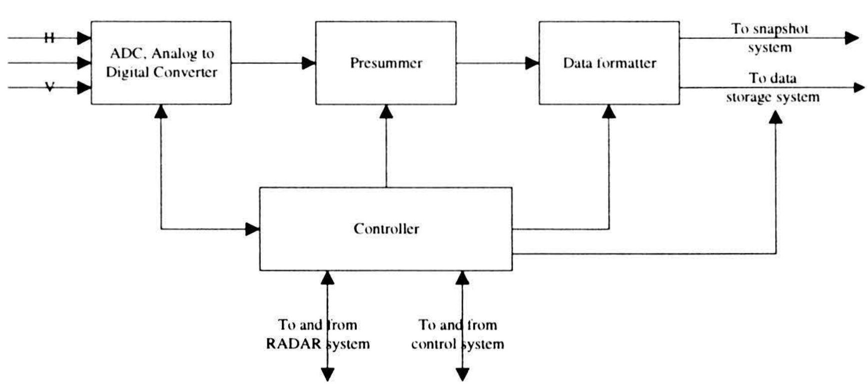
C.1 Flight trajectory system



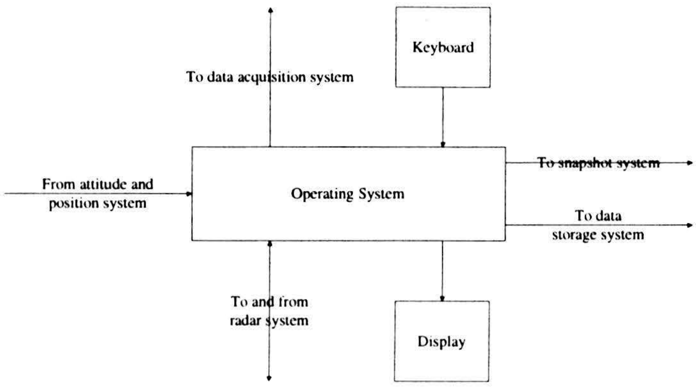
C.2 Radar system



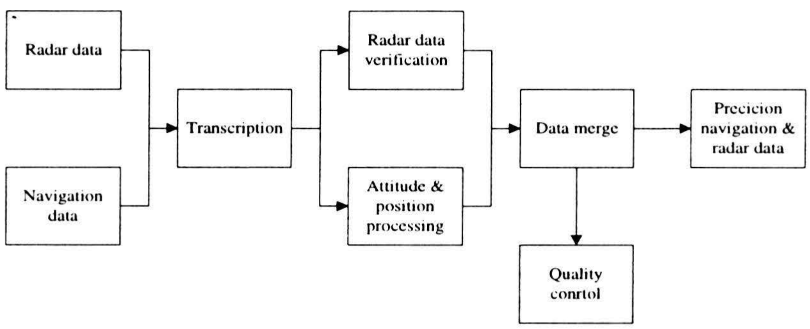
C.3 Data acquisition system



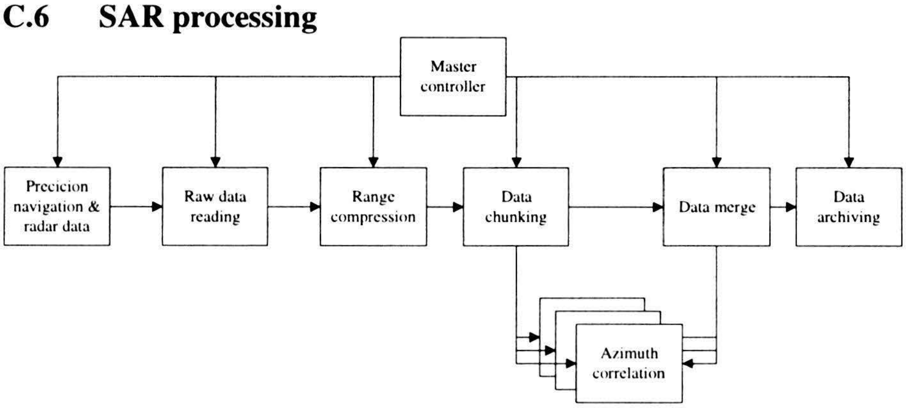
C.4 Control system architecture



C.5 On ground data preparation system

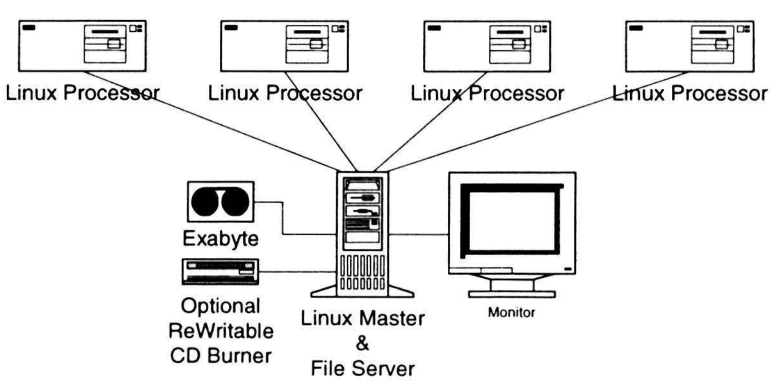


C.6 SAR processing



C.7 System Architecture

SAR processing will be done on a cluster of computers with a Master and Slaves.



Appendix D Mission profile

D.1 Forest management

With an area of approximately 3.4 million hectares, forests all around the world cover about 27% of the earth's surface. Utilisation of forest as a source of raw material is only one aspect. Also very important is their direct influence on the world's climate and ecosystem.

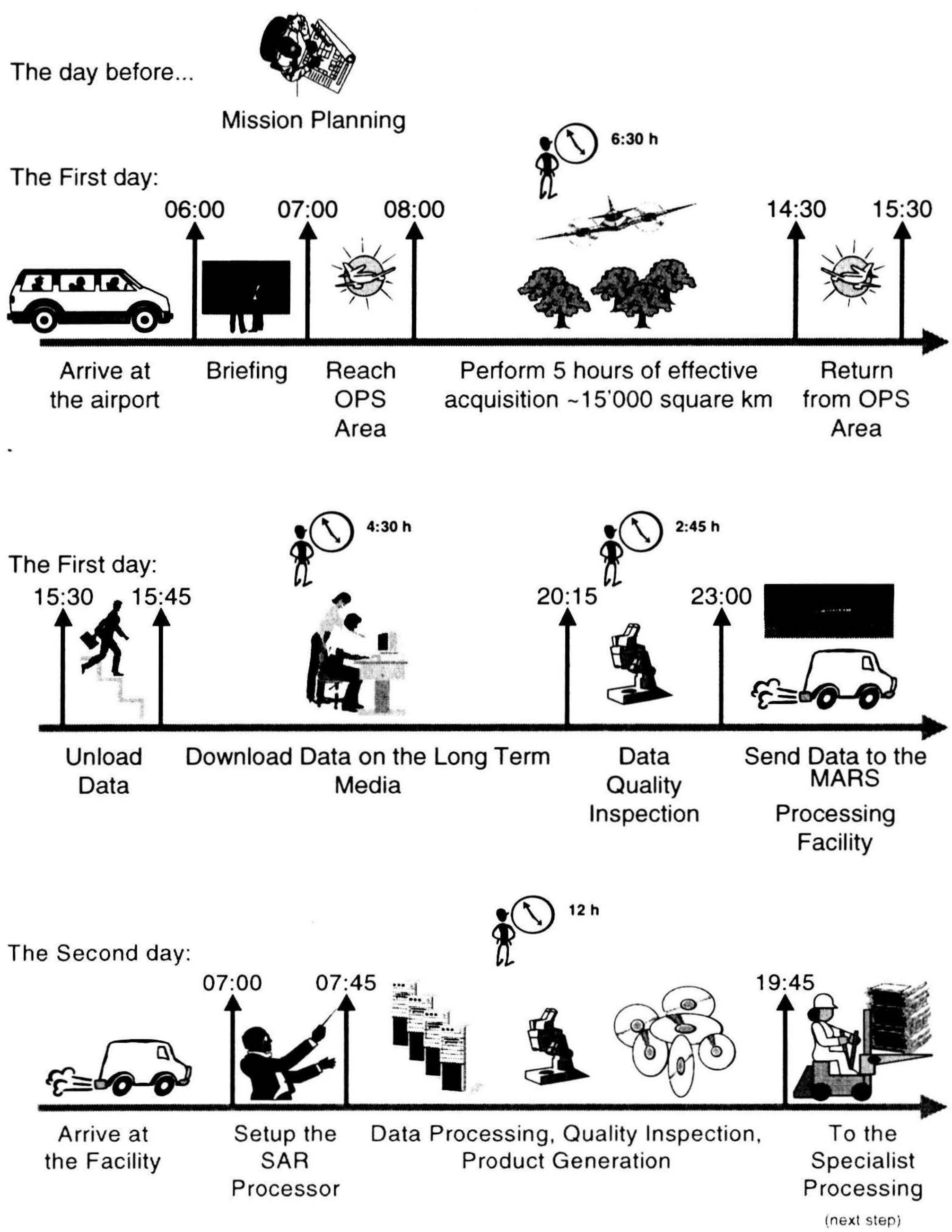
Forests, as part of the ecosystem, are getting more and more threatened and even partly destroyed by environmental pollution and deforestation. The area of tropical forest decreases and the ecosystems become poorer at an alarming rate due to shifting cultivation, uncontrolled logging and unplanned land use. The most serious problems occur in the zones of tropical rain forests. In order to improve the deteriorating tendency, utilisation of forest resources should be planned and controlled. In many developing countries basic information on forest resources and land use is typically very scarce; base maps, if existing, are old and inaccurate, and remotely sensed material is occasional. Data collection is difficult and ground measurements are expensive due to poor infrastructure.

Since remote sensing data are up-to-date and quickly accessible the effects of single events with big influence on forests, like storms or insect plagues, can be displayed easily and within a short time of the actual event. Applications of remote sensing for forestry are:

- Forest type classification and inventory
- Planning of forest care and logging activities
- Mapping of tree heights for timber volume and bio-mass estimation
- Forest health monitoring and change detection, e.g. deforestation, damage
- Infrastructure planning e.g. access and logging routes
- Monitoring of recultivation areas
- Fast, accurate, cost effective and homogeneous inventory and monitoring
- Reduction of financial loss by early detection of anomalies and quick implementation of countermeasures
- Proof of forest utilisation compliant to national and international regulations
- Efficient storm-damage assessments for insurance claims
- Guide to optimised ground-based surveys

Using remote sensing data allows making the current status of forests visible, even for large areas, and monitoring their changes over a period of time are the main applications where remote sensing data have become very useful. However, clouds hinder frequent use of optical satellite data in areas of most tropical forests. Traditional aerial photography is often too expensive and also hampered by weather conditions. Under these circumstances the all-weather capacity of SAR-sensors seems to be an important step ahead towards a permanent monitoring systems for the tropics.

D.2 Operational timeline



Appendix E RAMS analyses

E.1 Reliability analysis

In the reliability analyses consists of the following analyses:

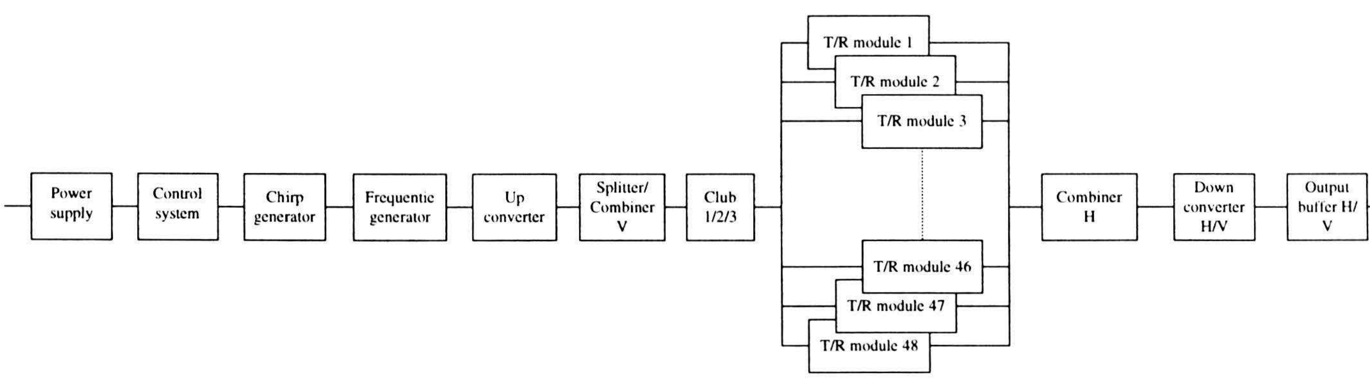
- Functional Block Diagram
- Reliability Block Diagram
- Reliability Prediction

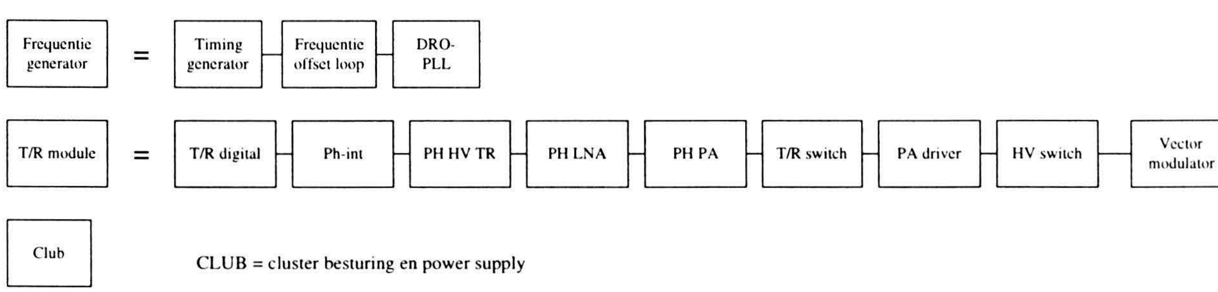
E.1.1 Functional Block Diagram

These diagrams are given in Appendix A

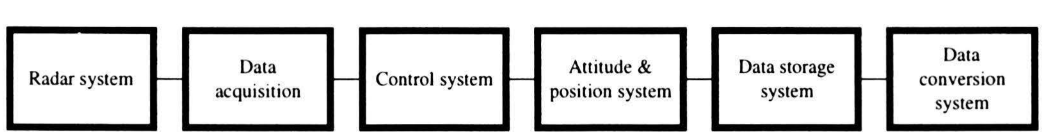
E.1.2 Reliability Block Diagram

Reliability Block Diagram of the RADAR system





Reliability Block Diagram of the Flight Segment



E.1.3 Reliability prediction

Reliability is the probability that an item can perform its intended function for a specified interval under stated conditions [10].

The probability that a component fails is assumed to be exponential distributed in time.
Reliability = $e^{-\lambda * t}$
Total operating time = t = 3300 hours (estimation shown in 3.2)
MTBF = Mean Time Between Failure (hours) = $1/\lambda$
Failure rate = λ
MTTF (mean time to failure) = $1/\lambda$ = expected lifetime

The data in the table, except for the splitter and the combiner H and V, come from failure rate data of the PHARUS from TNO. TNO made a Reliability prediction based on a partscount. The failure rates of the components come from MIL handbook 217E, with a temp of 50 °C and Stress Factor of 30 %. The environmental condition is A_{IC}, Airborne, Inhabited and Cargo. Not all failure rates are known yet. Nevertheless, this prediction gives an idea of the reliability of the radar. The failure rate of the splitter and combiner H and V was unknown because it was a special made splitter for PHARUS.

<u>T/R modules</u>

The radar exists of 48 T/R modules. The number of allowed failed T/R modules is determined on 5 modules. So 5 out of 48 T/R modules are allowed to fail without degrading the performance of the radar. To calculate the reliability of the T/R modules the following formula is used [24]:

$$P(K \le 5) = \sum_{0}^{5} \binom{48}{k} p^k (1-p)^{48-k}$$

$$= \sum_{0}^{5} \binom{48}{k} (1-R)^k R^{48-k}$$

<u>Splitter/combiner H and V</u>
To calculate the failure rate of the splitter and combiner H and V, the military handbook for electronic equipment is used. The calculations is made as follows:

$\lambda_p = \lambda_b[N_1 * \pi_c + N_2 * (\pi_c + 13)]\ \pi_q * \pi_E$ [Failures/10^6 Hours]

λ_p = prediction of failure rate;
λ_b = Base Failure Rate, printed wiring assembly;
N_1 = Quantity of wave soldered functional plated through holes;
π_c = number of circuit planes;
N_2 = Quantity of hand soldered plated through holes;
π_q= quality factor;
π_E =environmental factor = A_{IC}.

λ_p = 0,000041*[786*3,6+19(1+13)]*1*5=0,6346 failures/10^6 Hours

E.1.4 Reliability prediction on total operating time, campaign time and mission time

The multiplication of bold printed figures leads to the reliability of the radar system.

Reliability Prediction on 3300 operating hours = total life time of RADAR					**Reliability Campaign (165 hrs)**		**Reliability mission (5 hrs)**	
PART	**Failure Rate =λ (per million hours)**	**MTBF = 1/λ (*1000hours)**	**Reliability = $e^{-\lambda*t}$ (3300 h.)**	**1- R(3300)**	**Reliability = $e^{-\lambda*t}$ (165 h.)**	**1- R(165)**	**Reliability = $e^{-\lambda*t}$ (5 h.)**	**1- R(5)**
Power supply (1x)	3.04	327	**0.98996**	**0.01004**	**0.99950**	**0.00050**	**0.99998**	**0.00002**
Central control(1x)	5.45	183	**0.98213**	**0.01787**	**0.99910**	**0.00090**	**0.99997**	**2.73E-05**
Chirp Generator (1x)	8.90	112	**0.97097**	**0.02903**	**0.99853**	**0.00147**	**0.99996**	**4.46E-05**
Frequency generator (1x)	12.59		**0.95931**	**0.04069**	**0.99793**	**0.00207**	**0.99994**	**6.29E-05**
Timing generator	5.82	171	0.98089	0.01911	0.99904	0.00096	0.99997	2.92E-05
Frequency offset loop	5.96	167	0.98043	0.01957	0.99901	0.00099	0.99997	2.99E-05
DRO-PLL	0.75	1330	0.99752	0.00248	0.99988	0.00012	1.00000	3.76E-06
Up/down converter (3x)	4.25	235	**0.98606**	**0.01394**	**0.99930**	**0.00070**	**0.99998**	**2.13E-05**
Club (3x) .	6.80	147	**0.97780**	**0.02220**	**0.99888**	**0.00112**	**0.99997**	**3.40E-05**
Splitter = Combiner V (2x)	0.64	1576	**0.99791**	**0.00209**	**0.99990**	**0.00010**	**1.00000**	**3.17E-06**
T/R module	247.24		**0.44224**	**0.55776**	**0.96003**	**0.03997**	**0.99876**	**0.00124**
T/R digital	5.13	194	0.98313	0.01687	0.99915	0.00085	0.99997	2.58E-05
Ph-int	0.03	33900	0.99990	0.00010	1.00000	4.87E-06	1.00000	1.47E-07
PH HV TR	0.08	12100	0.99973	0.00027	0.99999	1.36E-05	1.00000	4.13E-07
PH LNA	0.65	1550	0.99787	0.00213	0.99989	0.00011	1.00000	3.23E-06
PH PA	3.76	266	0.98767	0.01233	0.99938	0.00062	0.99998	1.88E-05
FLM 5359-4b	180.00	5.55	0.55179	0.44821	0.97071	0.02929	0.99910	0.00090
FLM 5359-20p	41.80	23.9	0.87103	0.12897	0.99312	0.00688	0.99979	0.00021
T/R switch	5.09	196	0.98330	0.01670	0.99916	0.00084	0.99997	2.55E-05
PA driver	3.39	294	0.98884	0.01116	0.99944	0.00056	0.99998	1.70E-05
HV switch	5.27	189	0.98269	0.01731	0.99913	0.00087	0.99997	2.65E-05
PH VM (2x)	0.08	12900	0.99974	0.00026	0.99999	1.28E-05	1.00000	3.88E-07
Vector modulator (4x)	0.40	2500	0.99868	0.00132	0.99993	6.60E-05	1.00000	2E-06
T/R modules 5 out of 48	0.00		**1.00000**	**3.105E-08**	**1**	**5.27E-54**	**1**	**6.22E-119**
Combiner H (1x)	0.64	1576	**0.99791**	**0.00209**	**0.99990**	**0.00010**	**1.00000**	**3.17E-06**
Outputbuffer H + V/ IF amplifier (2x)	3.38	296	**0.98891**	**0.01109**	**0.99944**	**0.00056**	**0.99998**	**1.69E-05**
total reliability Radar system			**0.78885**	**0.21115**	**0.98821**	**0.01179**	**0.99964**	**0.00036**
Sum failure rates	71.79	13.930	**0.78906**	**0.21094**	**0.98822**	**0.01178**	**0.99964**	**0.00036**

The RADAR system has a reliability of 0.79 on a period of 3300 operating hours.

Reliability of one flight (= one mission) of five hours is:

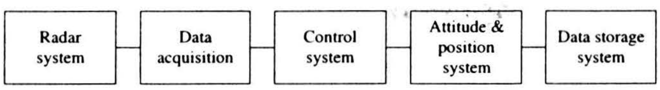
$$\text{Reliability}_{\text{mission}} = e^{-\Sigma\lambda*t} = e^{-71.79/1000.000*5} = 0.99964$$

So the probability that a flight is wasted is 0.00036.

E.1.5 Allocated reliability requirements for Flight assembly

The reliabilities of the different subsystems are calculated as follows:
Total reliability of flight assembly is the multiplication of the Reliability of RADAR system, Data Acquisition System, Control System, Data Storage System and Attitude and Positioning

System, see the next figure. The reliability of the Radar system is predicted and therefor the reliability of the other subsystem can be allocated.



A weigh factor is introduced to make a difference in the complexity of the systems, so the DAS is a more complex system then the data storage system and then the Attitude and Position System. With the complexity of figure of the system, a weighted failure chance is calculated.

Subsystem	**Weighted failure chance**	**Min. Rel. on 5 hours**	**Weighted failure chance**	**Min. Rel. on 165 hours**	**Weighted failure chance**	**Min. Rel. on 3300 hours**	**Complexity of system**
Radar system	0.00036	**0.9996**	0.0118	**0.9882**	0.2112	**0.7888**	50
Data Acquisition System	0.00011	**0.9999**	0.0035	**0.9519**	0.0633	**0.9656**	15
Data Storage System	0.00005	**0.9999**	0.0017	**0.9663**	0.0296	**0.9759**	7
Attitude & Position System	0.00002	**0.9999**	0.0007	**0.9856**	0.0127	**0.9897**	3
Control System	0.00018	**0.9998**	0.0059		0.1056		25
Total reliability flight assembly		**0.9993**		**0.9766**		**0.6332**	**100**

E.2 Maintainability analysis

E.2.1 Qualitative maintainability analysis

The FMECA is not completed yet, because of missing information. The information should come from a person who completely knows the design and the system.

E.2.2 FMECA

The following parameters are considered for the different functional failure modes:
- The pulse, which gives the time parameter;
- The frequency carrier, that carries the pulse to the ground;
- The chirp, which is a linear frequency (sweep) that codes the pulse;
- Amplitude van carrier;
- Frequency polarisation.

Severity
CAT = catastrophic: loss of life, loss of system
SER = serious: loss of mission, or serious injury
MAJ = major: partly loss of mission, minor injury
MIN = minor: due to failures and corrective maintenance, activities have to be postponed
NEG = negligible: Maintenance necessary but flight schedule not affected

Probability (system fails within campaign of 165 operating hours)
Probable ($>10^{-2}$)
Remote or improbable (10^{-4} .. 10^{-2})
Very remote, or extremely remote (10^{-5} .. 10^{-4})

Very improbable (10^{-6} .. 10^{-5})
Extremely improbable ($<10^{-6}$)

N.A. Not Available information

Remarks:
- Cost of one flight is dfl 25.000,-
- POD is filled with dry air (nitrogen) to prevent the radar system from corrosion and oxidation.
- Single point failures are: Chirp generator; Frequency generator; Up/down converter H/V; Splitter/combiner H/V; Outputbuffer H/V; Power supply; DAS; DSS and Control system.
- Club: if one or two Clubs fail, then only 2/3 (chance =0.9778011 on 3300 h.) or 1/3 (chance =0.99951) of the capacity.
- The subsystems which are not part of the flight assembly are not as important because these failure cause merely a delay in time but the flight schedule will not be affected.

The following measures should be taken in account for the maintenance concept:
1. The failures of the subsystems should be covered by BIT's! If not, then determine how fault detection and isolation should be done. For every subsystem the required test equipment should be determined.
2. Preventive maintenance for electronic systems is possible by calibrating the parts and will bring the subsystems back to specifications. So if possible, the systems should be calibrated every x operating hours. If the system is used longer then x operating hours the system will work outside the specifications. X should be determined for every subsystem.
3. The calibration equipment and test equipment, which is necessary, should be available in Indonesia.

Common causes for the electronic equipment in this case are:
- Electrical, because the total system consists of electrical systems;
- Temperature, because it is –50 degrees in the air and in Indonesia it can get up to 40 degrees;
- Vibration, because the radar is mounted under an aircraft.

Common causes are very dangerous for a redundant system. Because when one unit fails because of vibration, then the redundant units will probably fail by the same cause. So special attention must be paid to the common causes and failure modes of T/R modules. So far, no common modes have occurred.

Electronic systems have a constant failure rate, so if the subsystems do not fail in the beginning, then the chance of failure is very small under normal conditions.

FME CA#	Item	Function	Failure mode(s)	Cause(s)	Consequence(s)	Severity	Probability	Detection	Maintainability		Reliability Measures, recovery	Remarks/ recommendations
									Preventive	Corrective		
00	Radar	Acquires data of scanned area	A failure in any unit	Common modes/Common Causes CM/CC: Electrical, Temperature Vibration	No image, loss of mission	SER	$3.6*10^{-4}$	Yes, operator control	Replace, repair or calibration possible?	Replace or repair when broken?	The systems should be calibrated every x operating hours. Should be made possible in Indonesia.	Failures should be made visible during Flight. What equipment is needed for the calibration/reparation?
01	Chirp generator	Pulse generation	Longer or shorter pulses	Chirp generator has become unstable	Partly loss of mission	MAJ	$< 4.5*10^{-5}$	Snap shot system	No	Yes	System calibration can correct small differences	System analyser to get unit back into specification
			Different Sweep	Chirp generator has become unstable	Partly loss of mission	MAJ	$< 4.5*10^{-5}$	Snap shot system	No	Yes	System calibration can correct small differences	System analyser to get unit back into specification
			Fails	CM/CC	Loss of mission	SER	$4.5*10^{-5}$	Radar does not work	No	Yes	Replace failed component or part	
02	Frequency generator	generation of carrier	Lower or higher then 5.3 GHz	Frequency generator has become unstable	No influence, cause it is the carrier, which will not be processed	MAJ	$< 2.9*10^{-5}$	Snap shot system	No	Yes	As long as the frequency which is sent out is stored System calibration can correct small differences	Negligible, because it is only the carrier frequency
			Fails	CM/CC	Loss of mission	SER	$2.9*10^{-5}$	Snap shot system	No	Yes	Replace failed component or part	
03	Up converter/ Down converter H/V	Combines both signals to one	Doesn't convert the two signals	Wrong amplitude	Partly loss of mission	MAJ	$< 2.1*10^{-5}$	No	No	Yes	No	SYSCAL
			H does not work	CM/CC	Partly loss of mission	MAJ	$< 2.1*10^{-5}$	No	No	Yes	No	Negligible
			V does not work	CM/CC	Partly loss of mission	MAJ	$< 2.1*10^{-5}$	No	No	Yes	No	Negligible
			Fails	CM/CC	Loss of mission	SER	$2.1*10^{-5}$	No	No	Yes	No	Negligible
04	Splitter/ Combiner V/ Combiner H	Splits signal in 48 signals and combines 48 signals	Doesn't split the signals in equal parts	Weak or broken connectors	Partly loss of mission	MAJ	$< 3.2\ 10^{-6}$	No	No	Yes	No	Negligible
			Doesn't split in 48 signals	Weak or broken connectors	Partly loss of mission	MAJ	$< 3.2\ 10^{-6}$	No	No	Yes	No	Negligible
			Doesn't combine to 1 signal	Weak or broken connectors	If comb. V works then Single polarisation, which gives black white image	MAJ	$< 3.2\ 10^{-6}$	No	No	Yes	No	Negligible
05	T/R modules, 48	Transmits and receives signal, signal can be harmful to people	All fail	Impossible all t/r fail.	Loss of mission	SER	$<6.2*10^{-119}$	No	No	Yes	Safety measure for doing maintenance during active transmitting. See § 7.4 for the safety aspects	Negligible because of low probability
			>=5 fail	CM/CC	1-5 fail, not visual in image. If more fail, then it becomes visual, but not clear what the consequences are.	MIN	$6.2*10^{-119}$ that 5 fail	No	No	Yes	Modules divided in cluster of 16, BIT	But >5 fail, is negligible. One club fails $<10^{-3}$, 2 club fail $<10^{-6}$ etc.

FMECA#	Item	Function	Failure mode(s)	Cause(s)	Consequence(s)	Severity	Probability	Detection	Maintainability		Reliability Measures, recovery	Remarks/ recommendations
									Preventive	Corrective		
06	Club	Control and power supply for antenna	1 club fails	CM/CC	Partly loss of mission	MAJ	$4.46*10^{-5}$	No	No	No	Replace CLUB	Resolution becomes smaller because of a shorter Antenna. Lower flight altitude to compensate for shorter antenna
			2 club fail	CM/CC	Partly loss of mission	MAJ	$4.46*10^{-10}$	No	No	No	Replace CLUB	Negligible because of low probability
			3 club fail	CM/CC	Partly loss of mission	MAJ	$4.46*10^{-15}$	No	No	NO	Replace CLUB	Negligible because of low probability
07	Output buffer H IF amplifier	Converts radar signal into a signal for the data acquisition system	Fails	CM/CC	If only V works then single polarisation	MAJ	$1.7*10^{-5}$	No	No	Yes		
08	Output buffer V IF amplifier	Converts radar signal into a signal for the data acquisition system	Fails	CM/CC	If only H works then single polarisation	MAJ	$1.7*10^{-5}$	No	No	Yes		
09	Power supply	Supplies power to all subsystems	Fails	CM/CC	Loss of mission	SER	$< 2*10^{-5}$	No	No	Yes		Impossible; system switches to safe mode if wrong powers are generated
			Works degrades	Lower power or higher power	No	MAJ	$2*10^{-5}$	No	No	Yes		Impossible; system switches to safe mode if wrong powers are generated
10	Control system	Controls the tuning between Radar , data acquisition and data storage system	Wrong timing		Partly loss of mission	MAJ	N.A.	No	No	Yes	See for more elaborate description § 8.3.2	
			Fails		Loss of mission	SER	N.A.	No	No	Yes	See § 8.3.2	
			Communication failure		Loss of mission	SER	N.A.	No	No	Yes	See § 8.3.2	
11	Data acquisition system	Acquire the data from the radar	Fails		Loss of mission	SER	N.A.	No	No	Yes	See § 8.3.2	Two versions for H and V polarisation Only controller is single
12	Data storage system	Stores the data	Fails		Loss of mission	SER	N.A.	No	No	Yes	See § 8.3.2	
13	Attitude & position system IMU & GPS	Determine position of aircraft and acceleration	GPS fails		Partly loss of mission	MAJ	N.A.	No	No	Yes	See § 8.3.2	
			IMU fails		Partly loss of mission	MAJ	N.A.	No	No	Yes	See § 8.3.2	
14	On ground Data preparation system	Data pre-processing	Fails		Partly loss of mission or flight schedule postponed	MIN	N.A.	No	No	Yes	See § 8.3.3	Flight schedule is delayed
15	Ground System	Data Processing into image.	Fails		Negligible	NEG	N.A.	No	No	Yes	See § 8.3.3	Flight schedule is not delayed

FMECA#	Item	Function	Failure mode(s)	Cause(s)	Consequence(s)	Severity	Probability	Detection	Maintainability		Reliability Measures, recovery	Remarks/ recommendations
									Preventive	Corrective		
16	Pod 250 kg	Housing of RADAR	Leakage of pod	Mechanical Vibration Temperature (CM/CC)		MAJ	N.A.		Yes	Yes	Test under pressure	Hygrometer in Pod, to measure humidity See § 7.4 for the safety aspects
17	Mounting points	Mounting to aircraft	Break	CM/CC	Loss of radar system and possible loss of life	CAT	N.A.		Yes	Yes	Check for cracks in mounting, e.g. with dye-penetrant. Liquid that makes cracks visible with infrared. Screw can detach by vibration. Security mounting (double)	See § 7.4 for the safety aspects
18	Cooling system	Cools the temperature of radar system (< 60 ° C)	Temp. sensors do not work and cooling system is broke	CM/CC	The radar can work shorter periods. Faster wear out and corrosion	SER	N.A.	Temperature sensors	Yes	Yes		See § 7.4 for the safety aspects
			Expansion tank is broke	CM/CC	Partly loss of mission	SER	N.A.	Temperature sensors				
			Motor is broke	CM/CC	Partly loss of mission	SER	N.A.	Temperature sensors				
			Cooling fluid is gone	Cooling system doesn't work	Partly loss of mission	SER	N.A.	Temperature sensors	Yes	Yes	Temperature sensors	Periodically refill fluid
19	Temperature sensor	Control temperature in pod	Temp sensors work wrong	To warm, systems can fail, or damaged	Partly loss of mission	MAJ	N.A.	Redundant temperature sensors	Yes	Yes		Hygrometer in Pod, to measure humidity

E.2.3 Maintenance identification

MARS consists of the following electronic hardware:

Part	Preventive maintenance	Cycle time	Corrective maintenance	Is it possible to repair item?	COTS product?	Deliver-time	Costs	MTTR/ Down time	Replace time	BIT	Equipment for repair and replace	Equipment. For calibration	Equipment. for fault detection of unit	Eq. for fault detection within unit	Qualitative decline	Maintenance kind
RADAR	N	N.A.		Y	N	N.A.	N.A.			Y	Standard set of tools					
Chirp generator	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ Signal analyser	N	S.A.O.
Frequency generator	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ signal analyser	N	S.A.O.
Up converter	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ signal analyser	N	S.A.O.
Down converter H	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ signal analyser	N	S.A.O.
Down converter V	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ signal analyser	N	S.A.O.
Splitter = Combiner V	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ signal analyser	N	S.A.O.
Combiner H	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ Signal analyser	N	S.A.O.
48 T/R modules	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ signal analyser	N	S.A.O.
Output buffer H	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ Signal analyser	N	S.A.O.
Output buffer V	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	N	Standard set of tools	SYSCAL	Oscilloscope Multi meter	Spectrum/ signal analyser	N	S.A.O.
3 Cluster Control, club	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	Y	Standard set of tools	SYSCAL	Multi meter	N	N	S.A.O.
Power supply	N	N.A.	Y	Y	N	N.A.	N.A.	>1 day*	1 day	Y	Standard set of tools	SYSCAL	Multi meter	N	N	S.A.O.
Data acquisition system	N	N.A.	Y	Y	Y	N.A.	N.A.	N.A.	N.A.	N	Standard set of tools	N.A.	N.A.	N.A.	N	S.A.O.
Data storage System	N	N.A.	Y	Y	Y	N.A.	N.A.	N.A.	N.A.	N	Standard set of tools	N.A.	N.A.	N.A.	N	S.A.O.
Control system	N	N.A.	Y	Y	Y	N.A.	N.A.	N.A.	N.A.	N	Standard set of tools	N.A.	N.A.	N.A.	N	S.A.O.
Attitude & position system	N	N.A.	Y	Y	Y	N.A.	N.A.	N.A.	N.A.	N	Standard set of tools	N.A.	N.A.	N.A.	N	S.A.O.
On ground Data preparation system	N	N.A.	Y	Y	Y	N.A.	N.A.	N.A.	N.A.	N	Standard set of tools	N.A.	N.A.	N.A.	N	S.A.O.

Preventive maintenance:	Is Calibration, as preventive maintenance, of unit possible, to get the unit back into specifications?
Cycle time:	What is the cycle time in operating hours until the unit operates out of specifications?
Corrective maintenance:	Is corrective maintenance in Indonesia possible
Repair:	Is it possible to repair item?
COTS product:	Is the unit a COTS product and for how long will it be available?
Deliver-time:	What is the deliver-time of the unit?
Costs:	What are the costs of an unit?
MTTR:	What is the meant time to repair of the unit?
Replace time:	What is the time to replace the unit?
BIT:	Is the failing of a unit detected by the system?
Equipment for repair and replace:	What equipment is needed to replace and or replace the unit?
Equipment for calibration:	What equipment is needed to calibrate the unit, and to see if it is out of specifications?
Equipment for fault detection:	What equipment is needed to detect the failure within the unit?
Qualitative decline:	Does the system degrade because of maintenance?
Downtime:	What is the downtime caused by the failure of the unit? Downtime depends on the repair time and the transportation time.
SYSCAL	System calibration
N.A.	Not Available information
Standard set of tools	Set of tools to open and close radar, and change units, like screwdrivers etc.
S.A.O	Failure based maintenance
G.A.O	User based maintenance
T.A.O	Condition based maintenance

Mechanical parts need corrective and preventive maintenance.
About the following aspects no information is found. So these aspects are not included in the table.
Corrective Maintenance, Replace time, Costs per item, Deliver time MTTR
The pod consists mainly of mechanical units. The units are included in the following table.

The times are estimated, depending on the use and the experience, these times should be adjusted.
The times are adjusted to the campaigns. Because in between campaigns it is easy to take a break, so the overhauls must be planned according to the campaign times.

Part	Preventive Maintenance	Time between overhaul	Equipment/ tools	Kind of maintenance
POD, Radome	Y, leakage of pod, create over pressure to find out how serious the leakage is. Check rubbers every year, and replace if necessary.	Every year, 330 operating hours	Standard set of tools	S.A.O.
Mounting points	Y, visual check on cracks and screws Check with dye penetrant liquid on hair cracks.	Every year, 330 operating hours	Standard set of tools	T.A.O.
Cooling system	Y, visual check	Every year, 330 operating hours	Standard set of tools	G.A.O.
Motor	Y, Visual check, replace if necessary	Every year, 330 operating hours	Standard set of tools	G.A.O.
Expansion vat	Y, Visual check, replace if necessary	Every year, 330 operating hours	Standard set of tools	G.A.O.
Cooling liquid	Y, Visual check, replace if necessary	Every half year, 165 operating hours	Standard set of tools	T.A.O.
Lifting device	Y	Every year, 330 operating hours	Standard set of tools, oil	T.A.O.

E.3 Safety analysis

See paragraph 7.4 for the Safety analysis.

E.3.1 Hazard checklist

N.A. Not Applicable

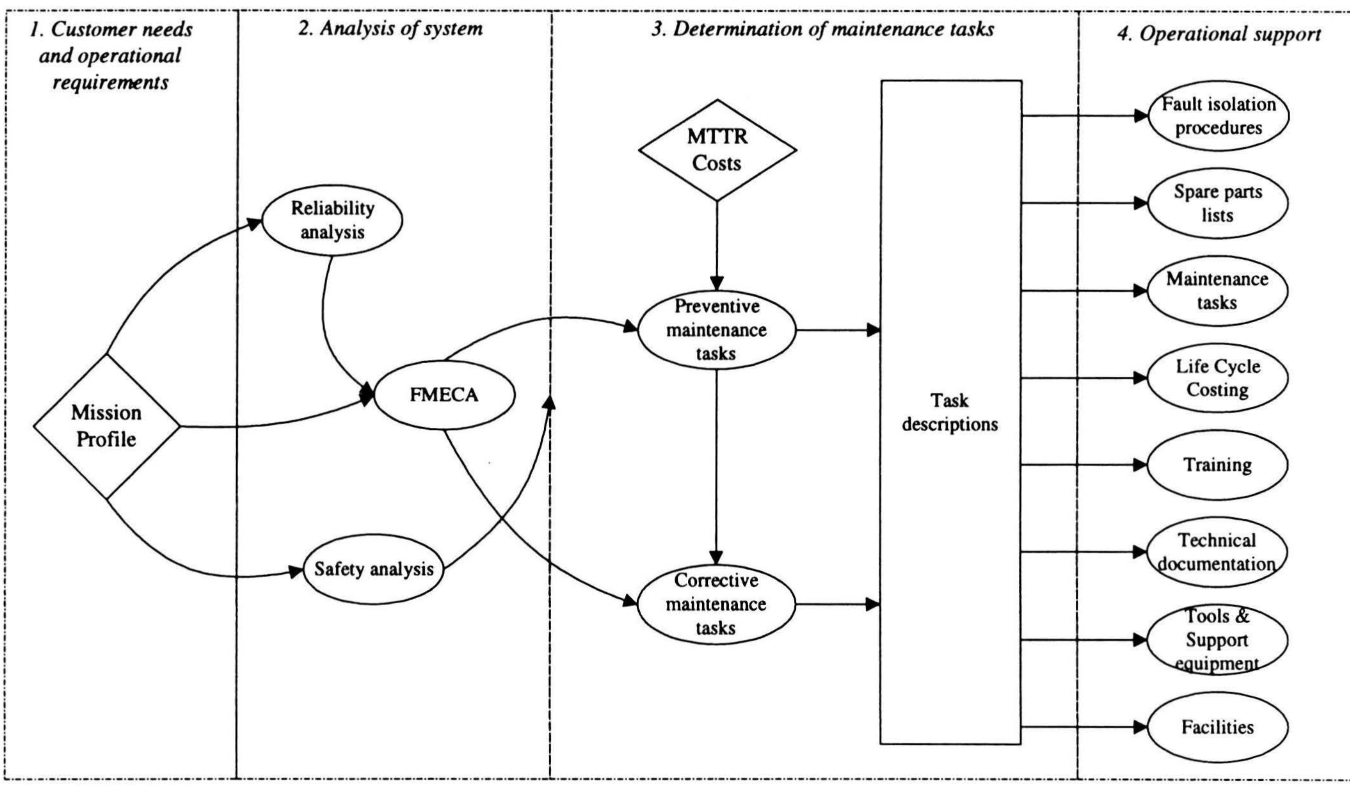
The hazards that are considered for the MARS flight segment are printed bold and with a shaded background.

Hazard Code	Hazard	Hazard Type	Possible influence on MARS or subsystems	Protection	Severity
AA	**Forces / Stresses**	**Mechanical**	**Pod, mounting. If mountings break, Catastrophic**	**RLD test, see § 7.4 for further explanation**	**CAT**
AB	**Mechanical Properties**	**Mechanical**		**RLD test**	**NEG**
AC	**Potential Energy**	**Mechanical**		**RLD test**	**NEG**
AD	**Kinetic Energy**	**Mechanical**		**RLD test**	**NEG**
AE	**Pressure**	**Mechanical**	**Pod**	**RLD test**	**NEG**
AF	**Vibration**	**Mechanical**	**Pod, mountings**	**RLD test, see § 7.4**	**CAT**
BA	**Electrical Current**	**Electrical**	**Radar system**	**Covered by BIT, if detected, then switches to safe mode (=OFF)**	**MAJ**
BB	**Magnetic Fields**	**Electrical**	**Radar system**	**Covered by BIT, if detected, then switches to safe mode (=OFF)**	**MAJ**
BC	**Static Electricity**	**Electrical**	**Radar system**	**Covered by BIT, if detected, then switches to safe mode (=OFF)**	**MAJ**
BD	**Voltage**	**Electrical**	**Radar system**	**Covered by BIT, if detected, then switches to safe mode (=OFF)**	**MAJ**
BE	**EMC**	**Electrical**	**Pod, radar**	**Transmit away from aeroplane**	**NEG**
CA	Light	Radiation	Antenna	Not applicable	N.A.
CB	**Radiation**	**Radiation**	**Antenna Person who performs maintenance, not sure what effects on health are**	**See safety analysis, § 7.4**	**SER**
DA	Asphyxiant	Chemical	Pod	not applicable	N.A.
DB	**Corrosiveness**	**Chemical**	**Pod, Cooling system**	**Flush with dry air**	**MAJ**
DC	Explosivity	Chemical	Pod	not applicable	N.A.
DD	Flammability	Chemical	Pod, radar	not applicable	N.A.
DE	Irritant	Chemical		not applicable	N.A.
DF	Toxicity	Chemical		not applicable	N.A.
DG	Chemical Compatibility	Chemical		not applicable	N.A.
EA	**Temperature**	**Thermodynamic**	**Radar, pod, tapes**	**Cooling system and temperature sensors**	**MIN**
EB	**Thermal Conduction**	**Thermodynamic**		**not applicable**	**N.A.**
FA	**Lightning**	**Earth Environment**	**Pod,**	**RLD**	**NEG**
FB	Fire	Earth Environment	Ground system	not applicable	N.A.
FC	Flood	Earth Environment	Ground system	not applicable	N.A.
FD	Wind	Earth Environment	Ground system	not applicable	N.A.
FE	Earthquake	Earth Environment	Ground system	not applicable	NEG
FF	**Humidity**	**Earth Environment**	**Tapes, Pod, faster corrosion if pod is not totally closed On ground data preparation system**	**Flush with dry air Check under pressure, how sever leakage is Store air-conditioned**	**MAJ**
FG	**Temperature**	**Earth Environment**	**Radar system**	**Cooling system and temperature sensors**	**MIN**
FH	Microbes	Earth Environment		not applicable	N.A.

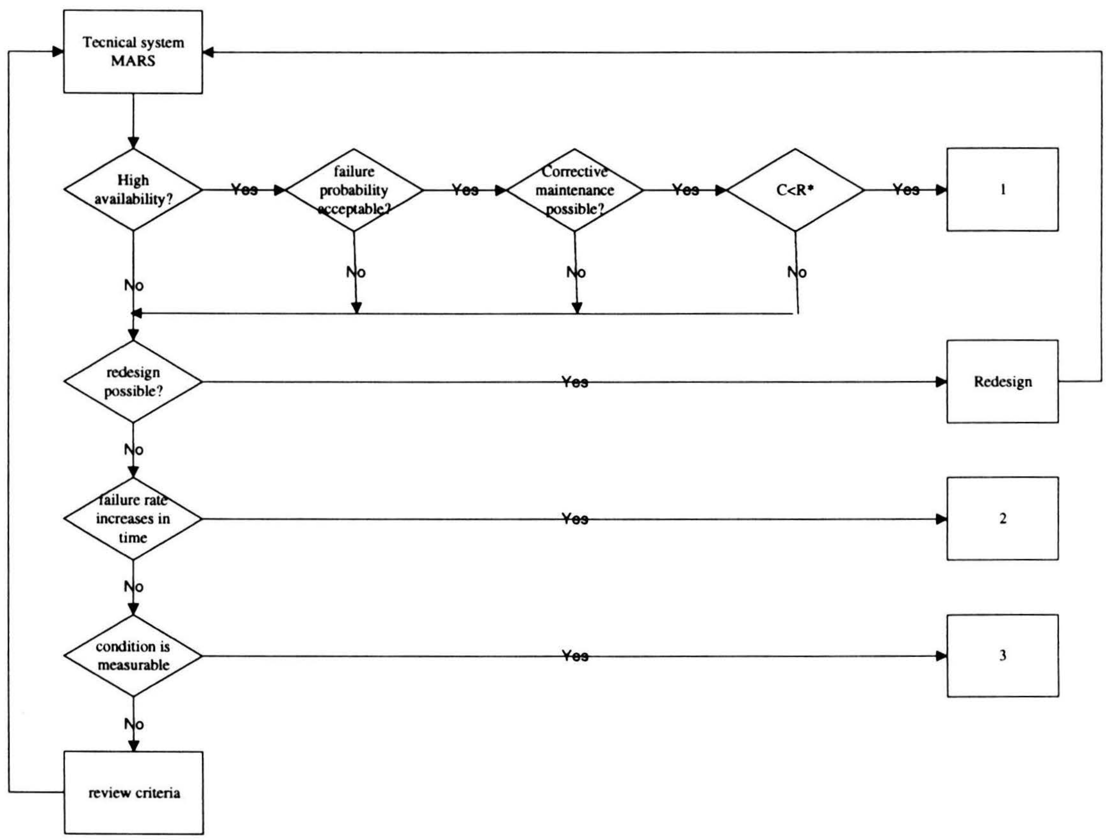
Appendix F Maintenance concept

F.1 How to develop a maintenance concept

To develop a maintenance concept information about repair times and cost are needed to determine what the most cost and time effective rules are. In the following diagram is shown what information is required to develop an effective maintenance concept and what information should be included in a maintenance concept. Parts like fault isolation procedures, maintenance tasks, technical documentation, tools & support equipment and facilities should be specified and provided by a subcontractor if a system is purchased. Subcontractors should specify the maintenance concept when they deliver the purchased systems.



F.2 Maintenance decision diagram [19]



C<R* Costs of damage by failure are higher than costs of redesign of MARS

1. Failure based maintenance policy (implies corrective maintenance);
2. User based maintenance policy (implies preventive maintenance as a quantity of time);
3. Condition based maintenance policy (implies inspection or examination of system, and depending on the result of check, a maintenance actions is initiated).

F.3 Maintenance flowchart