Knowledge Based Management For Rotating Equipment Diagnostics

By

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Dissertation Report submitted in partial fulfilment of
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AUNG MYINT OO

ABSRACT

Knowledge based management system for rotating equipment diagnostics is a expert system to help the maintenance engineers in the power plants or gas plants using gas turbines for power generation. Industrial gas turbine (Rolls – Royce Allison 510 – KB7) is used as the emphasis of the project to develop the application. Case based Reasoning and Spiral Life Cycle model are used as the methodology in this project for the methods can support and fulfil the objectives of the project. Microsoft Access and Java runtime are used for the database set up and system development respectively. The final system offers eight different scenarios for gas turbine diagnostics. Reference tables and Scenario note function The system is effective and less time consuming, platform(operating system) independent, easy to use and should be helpful for the maintenance engineers. Diagnostics for the auxiliary system of the gas turbine should be incorporated in the system to have a more complete system. MySQL database system should be used in the future development if the database is to expand.

ACKNOLEDGEMENT

I would like to take this opportunity to express my utmost gratitude to the individual that have taken the time and effort to assist me in completing the project. First and foremost, my utmost gratitude goes to my supervisor, AP. Ir. Dr. Shaharin A. Sulaiman. Without his guidance and patience, I would not be succeeded to complete the project. And, I would like to express my heartfelt gratitude to my industrial advisor Mr. M Shahrizal B Jasmani who assisted me throughout the project. A warmth thankful to the Final Year Project Coordinator, Mr. Mohd Faizairi B Mohd Nor for provide me with all the initial information required to begin the project. Last but not least, thanks to all individuals that has helped me in any way, but whose name is not mentioned here.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

A gas turbine is a machine delivering mechanical power or thrust by using a gaseous as working fluid. The mechanical power generated can be used by an industrial device. The output of the turbine is used to turn the compressor which may also have an associated fan or propeller. The hot air flow leaving the turbine is then accelerated into the atmosphere through an exhaust nozzle to provide power.

Gas turbines will be one of the most important horizontal technologies and will play an essential role in meeting requirements of today's demanding conditions. Gas turbine technology is considered horizontal due to its capacity to be widely applied across many different types of power plant configurations while running with different fuels (coal gas, natural gas, hydrogen, liquid fuels, etc.). This is in contrast to vertical technologies, such as coal processing, that are obviously only suitable for specific types of plant configurations and fuels. The advantages of using gas turbines can be listed such as –

- Competitive economic performance (i.e., higher efficiency and optimized life-cycle cost).
- Reliable operation under a duty cycle (repeated gas turbine startups and shutdowns).
- Increased dependability of current and future plants (reliability, availability, maintenance, and durability, or RAM-D).
- Ability to meet regulatory emissions levels and achieve high thermal efficiencies.
- Reliable fuel-switching capability and fuel flexibility.

An aero-derivative gas turbines i.e.; a lighter weight unit derived from an aircraft jet engine. Heavier weight units designed specifically for land use are called industrial or frame machines. Although aero-derivative gas turbines are being increasingly used for base load electrical power generation, they are most frequently used to drive compressors for natural gas pipelines, power ships and provide peaking and intermittent power for electric utility applications. Industrial gas turbines differ from aero-derivative in that the frames, bearings, and blading are of heavier construction.

Industrial gas turbines range in size from truck- mounted mobile plants to enormous, complex systems. They can be particularly efficient—up to 60%—when waste heat from the gas turbine is recovered by a heat recovery steam generator to power a conventional steam turbine in a combined cycle configuration. They can also be run in a cogeneration configuration: the exhaust is used for space or water heating, or drives an absorption chiller for cooling or refrigeration. Such engines require a dedicated enclosure, both to protect the engine from the elements and the operators from the noise.

Knowledge based management systems (expert system) is simply custom-written computer programs that are expert in some narrow problem area, and embody true human knowledge, experience and problem-solving strategies. KBM systems have been used in many problem areas, such as medicine, chemistry, geology, meteorology, computer systems, etc. KBM systems can generally be used in problem areas that:

- do not require common sense to solve
- are well understood
- data that is input to the expert system can be described objectively
- Human expertise is scarce
- Expertise needed in many locations, or in hostile environments
- there are considerable advantages in reaching an accurate answer quickly

KBM system aids a person in problem solving an area that he/she is unfamiliar in, or is inexperienced in. The system is combination of related information for particular area and algorithm to produce a desired result.

1.2 Problem Statement

The maintenance of rotating equipment, particularly gas turbines, in plants is very costly. The related maintenance team may be knowledgeable in their work. However, there are so many factors involved in a gas turbine that can lead to wrong judgement by the maintenance engineers. For complex systems, such as gas turbines, the occurrence of unexpected component failures drastically increases maintenance costs associated with corrective tasks not only for the direct corrective costs (spare parts, labour hours) but also for the system unavailability cost. Improvement of maintenance management of diagnostics of gas turbines through the use of historical maintenance data can enhance the reliability and availability of the systems and consequently support the plant operation and improve the yield and return.

1.3 Objective

The objective of this work is to: To develop a knowledge based management (KBM) for diagnostics of gas turbines. Diagnostic systems for Gas Turbine are sophisticated, expensive and hard to develop. A system using available troubleshooting manuals, sorted with fault tree analysis and algorithm for effective diagnostics and troubleshooting to aid in diagnosing process for the maintenance engineers.

1.4 Scope of Study

The scope of study of the project involved would be on towards gathering information on to review the previous related work on KBM systems and gas turbine diagnostic and historical maintenance/diagnostic data for gas turbines takes precedence to build the database for use. Information gathered from the plants and data analysis is to design the algorithm for the KBM. Java runtime is used to develop the system. The expected end product is to test the developed system.

1.5 Significance of Project

Approximately half of all operating costs in most processing and manufacturing operations can be attributed to maintenance. This is ample motivation for studying any activity that can potentially lower these costs. Gas Turbines are massive and sophisticated systems with continuous operating cycle times. Preventive maintenance system sensors are equipped in all the gas turbines to raise warning signals to avoid system downtime. Preventive maintenance functions only to warn of the situation not directly specify the problem. Knowledge based management system will take advantage of the warning provided from preventive maintenance to aid in diagnosing process. Gas Turbine suppliers provide troubleshooting manuals to the customer as to inform and familiarise with system configuration and to help in maintenance. These manuals only are provided with in paper format and it would be time consuming process to go through the whole manual at every situation. Digitising the manuals is one alternative for ease of use and time effective process .Using simplex algorithm and database system can be much useful and effective in diagnosing.

CHAPTER 2
THEORY

2.1 Gas Turbine

Gas turbine engines are, theoretically, extremely simple. They have three parts:

- Compressor - Compresses the incoming air to high pressure
- Combustion - Burns the fuel and produces high-pressure, high-velocity gas
- Turbine - Extracts the energy from the high-pressure, high-velocity gas flowing from the combustion chamber

Air is sucked in from the right by the compressor. The compressor is basically a cone-shaped cylinder with small fan blades attached in rows (eight rows of blades are represented here). Assuming air at normal air pressure, then as the air is forced through the compression stage its pressure rises significantly. In some engines, the pressure of the air can rise by a factor of 30.

This high-pressure air then enters the combustion area, where a ring of fuel injectors injects a steady stream of fuel. The fuel is generally kerosene, jet fuel, propane or n-atural gas. There is the design problem in the combustion area - entering this area is high-pressure air moving at hundreds of miles per hour. The can, also called flame holder, is a hollow, perforated piece of heavy metal. Compressed air enters through the perforations. Exhaust gases exit at the left. A set of cylinders wraps around the inside and the outside of this perforated can, guiding the compressed intake air into the perforations.

In the turbine section there are two sets of turbines. The first set directly drives the compressor. The turbines, the shaft and the compressor all turn as a single unit. The final stage turbine drives the output shaft. This final turbine stage and the output shaft are a completely stand-alone, freewheeling unit. They spin freely without any connection to the rest of the engine. There is enough energy in the hot gases blowing through the blades of that final output turbine to generate 1,500 horsepower.

2.2 Case-Based Reasoning (CBR)

For research element of study, process of Case-based Reasoning will be the main process method to determine the problem faces from previous existing similar problems and find solutions for the new found problems. Several steps needs to be followed using CBR that relates to this project are:

1. Retrieve case: Supposed that KBM system is going to perform a diagnostic run for rotating equipment. User will be asked to provide the system with the measured data profiles and machine behaviour. Based on the similarities between the stored data and provided data system will find the most relevant case.
2. Reuse: KBM system needs to map solutions from previous case problems stored in the database and target it to the new problem. This may involve adapting solution to new situation.
3. Revise: KBM system needs to target which situation needs to be solve base on previous problems and test for the new solution.
4. Retain: When KBM system found the solutions to the target problem, the result will be stored as a new memory of problem and solutions.

2.3 Spiral-Life Cycle Model

In this project, Spiral Model has been choose as the most suitable method to be perform for Knowledge Based Management system development process.

Steps involve in Spiral Model that relates to this project are:

1. Information requirement for KBM will be determined as detail as possible. Some survey and interview will be conduct in order to make user friendly and external expectation and other aspects of the system.
2. Design draft feature for KBM system is created.
3. A prototype is based from the draft of new system created. This is usually a scaled-down system, and represents an approximation of the characteristics of the final product.
4. A second prototype evolved from the first prototype created following some procedure:
   - evaluating the first prototype in terms of its strengths, weaknesses, and risks;
   - defining the requirements the prototype;
   - planning and designing the prototype;
   - constructing and testing the prototype.

CHAPTER 3
LITERATURE REVIEW

Due to the importance of the gas turbines in the power generation, it is critical that to prevent the unprecedented shutdowns and breakdowns which can hinder the plant process. The subject of machine diagnostic is charged with developing new technologies to diagnose the machinery problems. Different methods of fault identification have been developed and used effectively to detect the machine faults at an early stage using different machine quantities, such as current, voltage, speed, efficiency, temperature and vibrations. Through the use of different signal processing techniques, it is possible to obtain vital diagnostic information from vibration profile before the equipment catastrophically fails. A problem with diagnostic techniques is that they require constant human interpretation of the results. The logical progression of the condition monitoring technologies is the automation of the diagnostic process. The research has been underway for a long time to automate the diagnostic process. Recently, artificial intelligent tools, such as expert systems, neural network and fuzzy logic, have been widely used with the monitoring system to support the detection and diagnostic tasks. Attempts are made to highlight the current and future issues involved for the development of automatic diagnostic process technology.[Singh and Al Kazzaz, 2003]

Proper selections of measurement parameters, which provide crucial information, one of the integral parts in GPA for ensure accuracy in diagnostic results. In gas turbines, there are not much sensors usually equipped only a few to be informed of the parameters profile for the purpose of engine control and protection. The need of a set of parameter measurements, which are carefully chosen to get the reliable diagnostic results, with of high accuracy play crucial role in developing the effective diagnostic system. Thus, the true purpose of GPA measurement selection process is to determine the engine measurement sets that produce high accuracy in predictions of gas turbine gas path component degradation.[Jasmani, Li and Ariffin, 2011]

A problem with diagnostic techniques is that they require continuous human input for the results. The logical advancement of the condition monitoring technologies is the automation of the diagnostic process.[Jardine, Lin and Banjevic, 2006]

Data review, hypothesis generation and hypothesis confirmation of the process is automated by CBR system, whenever to aid the user in situations such as there is number of factors instead of one single cause. By implementing the CBR system in the knowledge engineering and data acquisitions stages as a solution to the diagnosis problems, the amount of human effort required for updating and maintaining the system is reduced to considerable amount. Rule or model-based approaches usually depends on very extensive knowledge engineering efforts by experts well versed in the appropriate techniques in conjunction with subject matter experts in order to develop an application. Furthermore, once that application is utilised in a dynamic changing real-world environment these techniques require the same personnel to monitor and update the system in order to maintain an acceptable level of performance. Case-based reasoning, in contrast, is amenable to automated maintenance, in which a “meta-reasoning” component of the architecture continually monitors the inputs and outputs of the system and makes modifications to the case-base autonomously in order to preserve currency with a changing application domain.[Devaney and Cheetham, 2005]

Systems, developed around the world for various reasons, are mostly sophisticated and complex. Prognosis usually takes precedence in those systems rather than diagnosis which make the system difficult to develop. A system only for diagnostic and maintenance solution can assist the plants and factory with no capabilities of real-time monitoring and advanced machinery.

CHAPTER 4

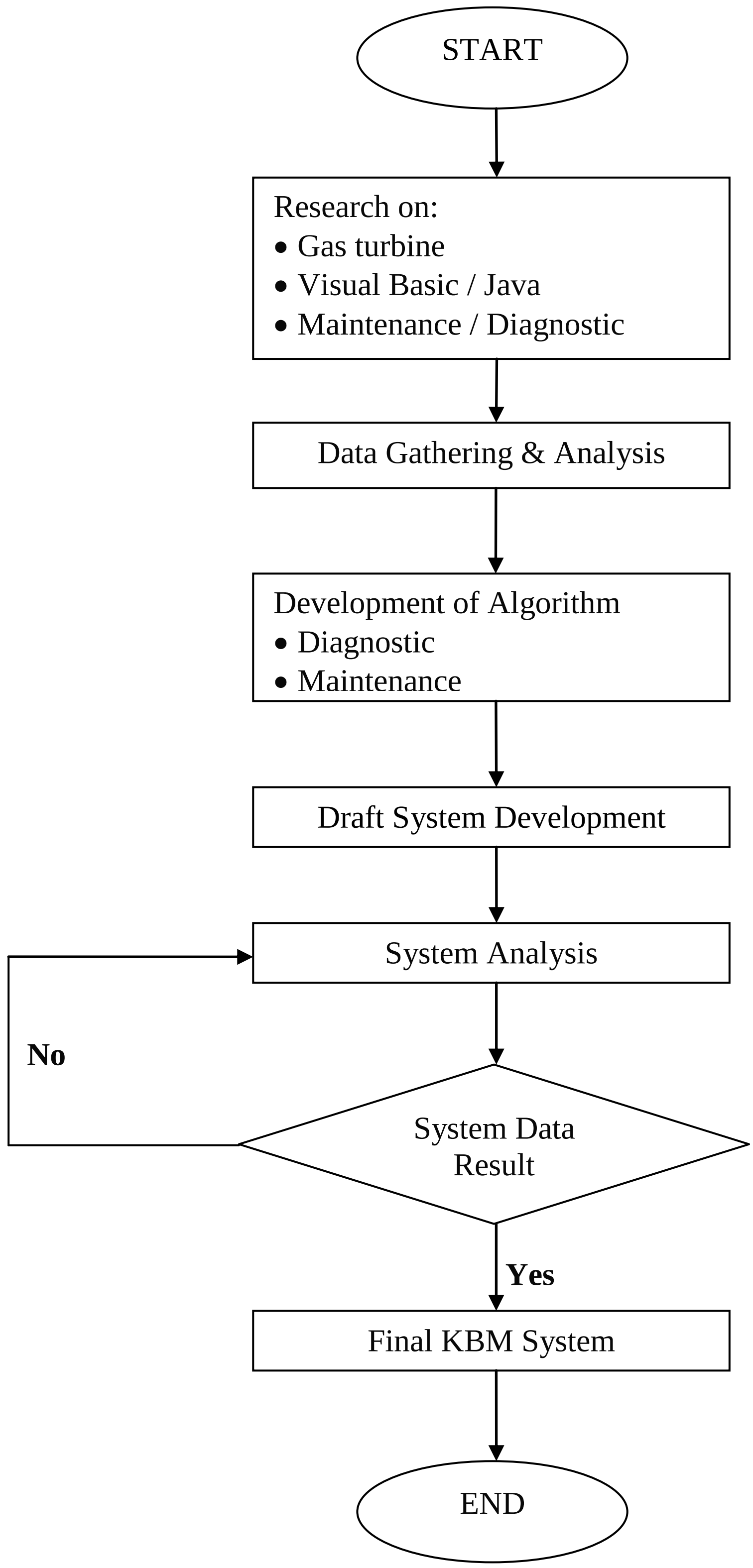
METHODOLOGY

Developing knowledge based management for gas turbines especially for diagnostic purposes requires dealing with a lot of information on the working theory of gas turbines, diagnostics methods, parameters needed and programming knowledge of Java runtime to develop the algorithm. This through research on the required subjects is first step of the project.

Diagnostics information can be constructed based on the design information and interpretations from the temperature and pressure profiles at various point. Data gathering and analysis stage will utilise cased based reasoning (CBR) technique as discussed in chapter 2. The resulted information from the stage two will incorporate in stage three, development of algorithm, by using fault tree analysis.

Visual Basic will be used to develop the system with the algorithm developed at stage three. System interface, user friendliness, easy access, effective diagnostics are the key issues to address in this final stage. Spiral Life Cycle model (chapter 2) will be used to develop the system. The work flow can be seen in the following execution chart. Microsoft Access, Java Runtime Environment are used as tools for the system development.

3.1 The Work Flow (Execution Chart) & Gantt Chart



Work flow chart

No	Task Name	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Preliminary Research Work							MIDSEM BREAK							
2	Research & Data Collection														
3	Analysis														
4	Algorithm Design														
5	Draft system development														
6	Algorithm Design														
7	System development														
8	System evaluation														

Gantt chart

CHAPTER 5
RESULTS & DISCUSSIONS

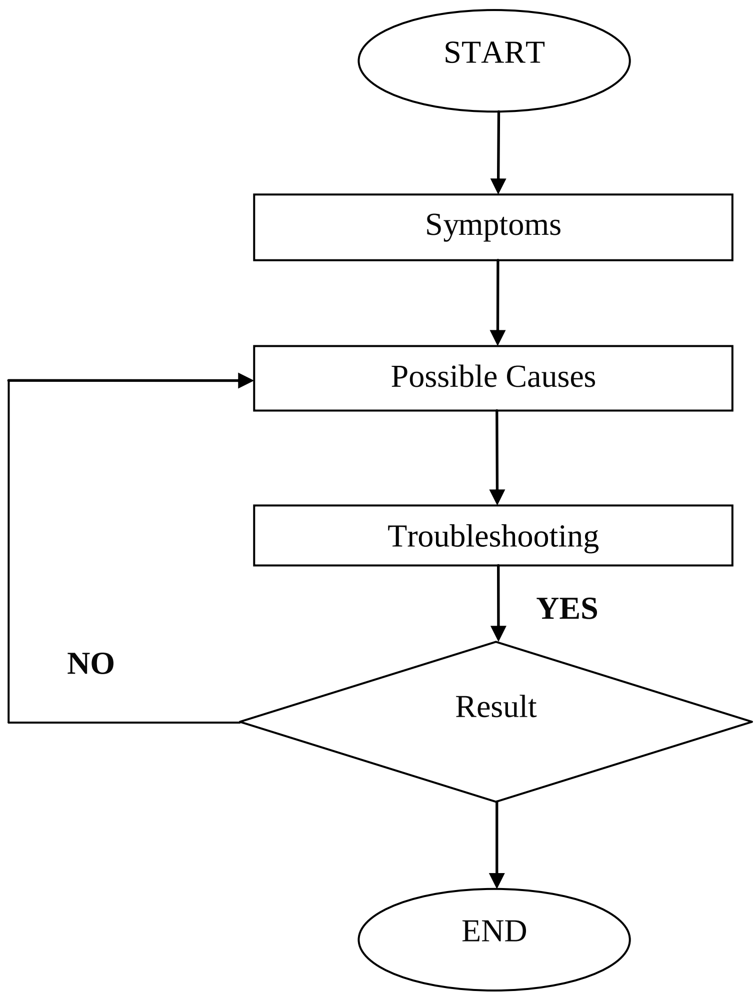
An ultimate outcome of the project is to develop a functioning knowledge based management system for rotating equipment diagnostics. As the project emphasise on gas turbines and requires of design information and field knowledge and experience of the maintenance engineers.

A draft algorithm and system development is based on the information available from troubleshooting manual provided by the management of Gas Plant (Myaung Ta-Gar), operated by Ministry of Energy from Myanmar. The outcome of the draft system serves as the very basic and simple diagnostics system. The final system uses troubleshooting manual for Rolls - Royce Allison 501 - KB7 from Petronas Carigali Sdn Bhd, Terengganu.

Gas Path Analysis was considered as a future development of the system. Due to the restricted information and suggestion from Industrial Advisor, GPA was left out and other possible alternatives were taken into account. Troubleshooting manuals provided by the gas turbine suppliers can aid to develop the system. The manuals only comes in paper format and with help of simple algorithm, these information can be much helpful to the maintenance engineers.

Microsoft Access is used to set up the database to use in the system. Problems which likely to occur and diagnosis and solutions to overcome the particular problem are recorded with assigned interlink format.

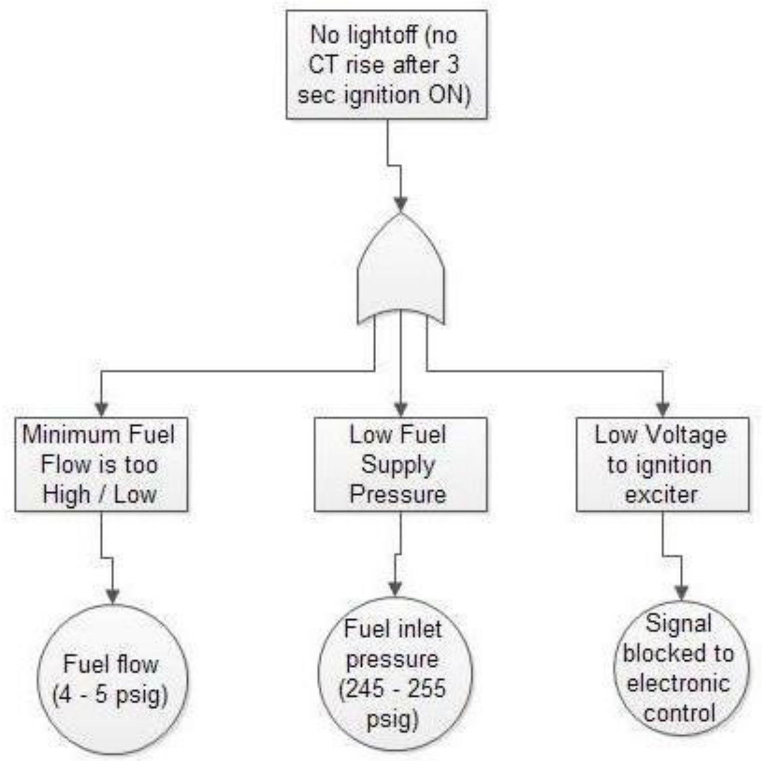
Visual Basic was proposed as a programming language for system which mainly used in database systems. Knowledge based management system should be platform(operating system) independent, easy to access, user friendly and easy to update the database. Java runtime offers more flexible and easy way to develop the system and meet requirements of the system. Algorithm works with three steps to diagnose the problem at hand. Following flow chart shows how the system works.



Algorithm diagram

The algorithm applies to all the scenario and works simply to direct and help diagnosis the problem at hand for the engineers. Example of implementing this algorithm to the problems using fault tree analysis is shown in the following chart.

Troubleshooting manuals are not easily available and considered as confidential document. More comprehensive and complete manual can aid the system to be much more effective. The system can only diagnose the problem in general way and offer possible cause. Further troubleshooting steps are not included.



Fault tree analysis diagram

5.1 Diagnostic Tool

Diagnostic tool for gas turbine can help in eight scenarios and its possible causes. Following figures show how the system can be used. Possible causes are listed as shown in the fault tree analysis figure. Same example scenario is shown in the figures for better clarification.

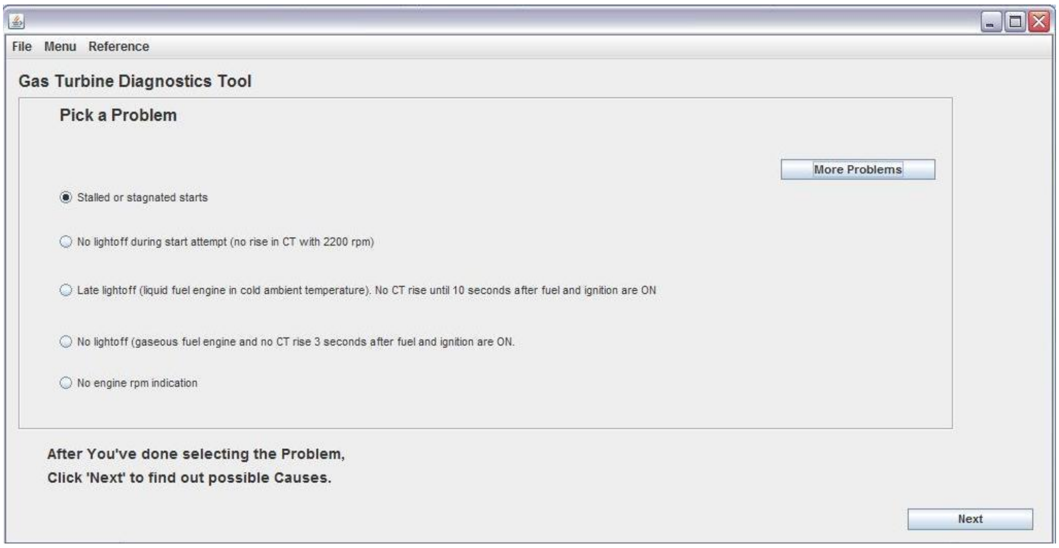


Figure 5.1: Problem Identification

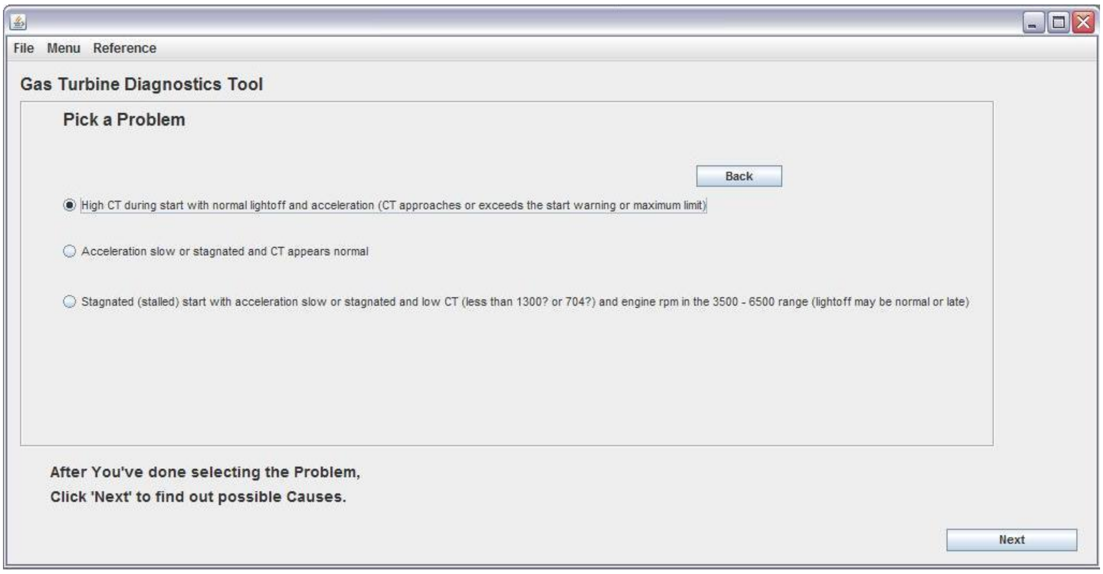


Figure 5.2: Problem Identification

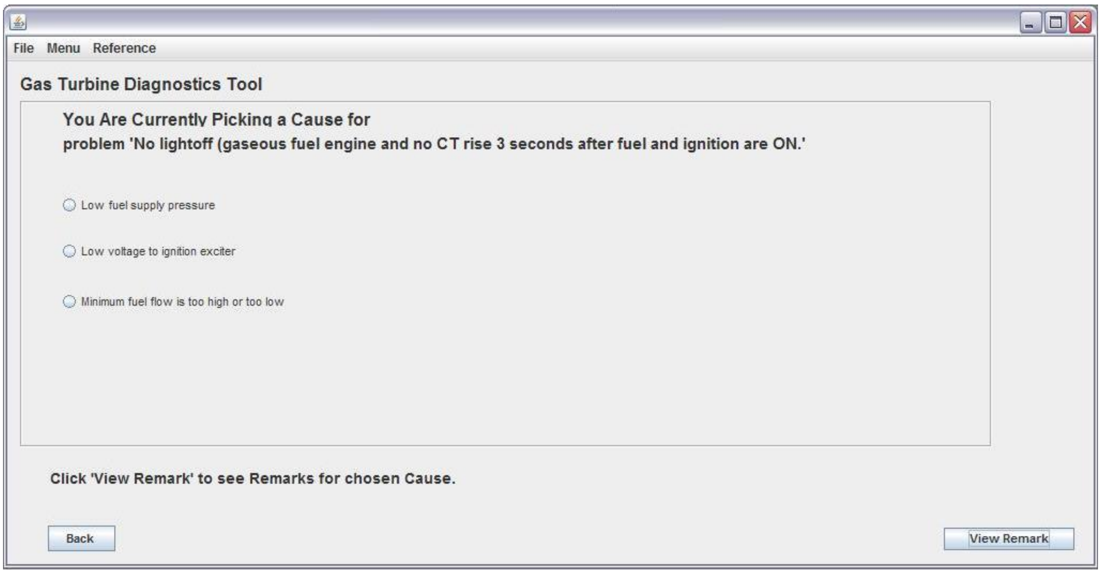


Figure 5.3: Possible causes

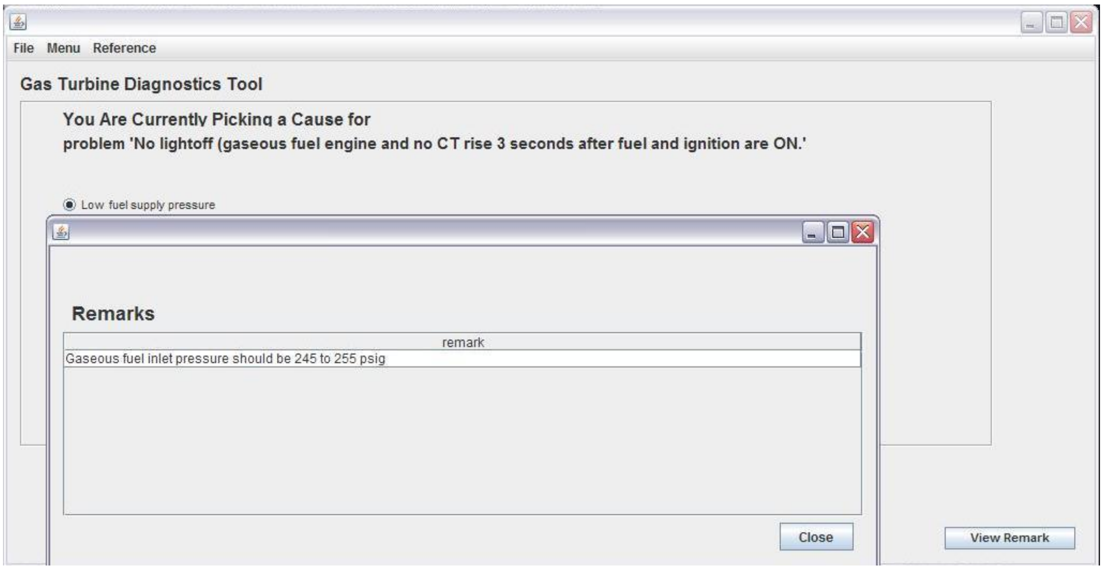


Figure 5.4: Troubleshooting

5.2 Special Inspection Tool

Special inspection tool is used to when there is a malfunction or pending malfunction as indicated by warnings.

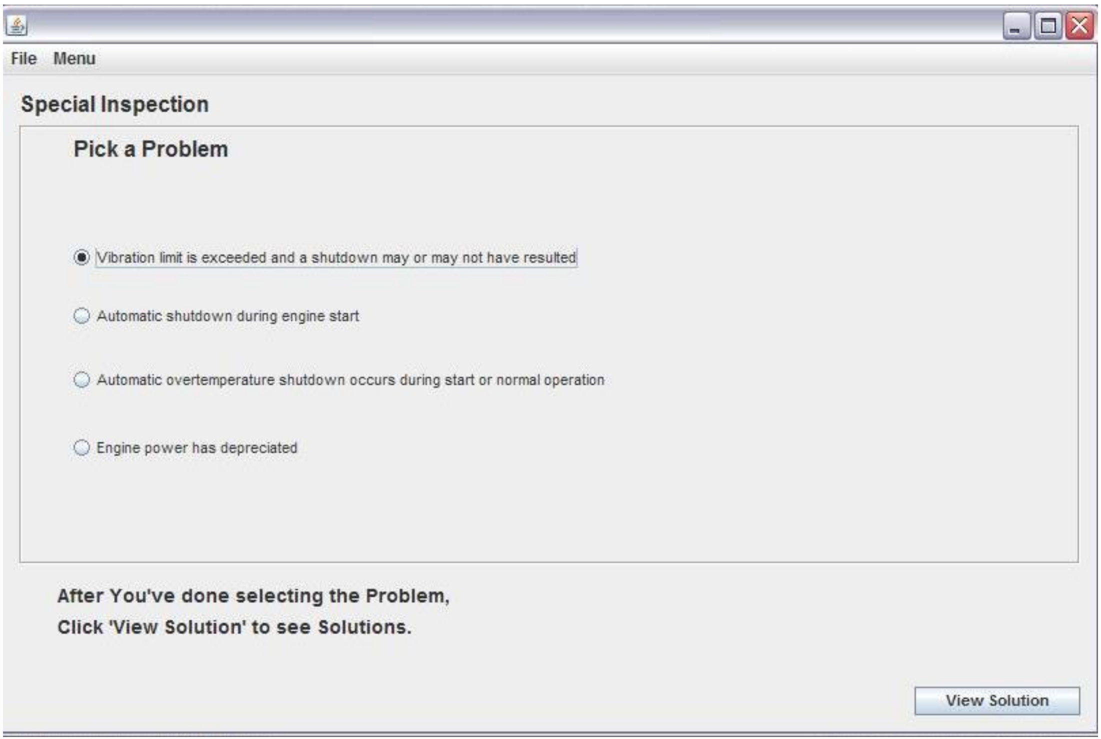


Figure 5.5: Problem Identification (special inspection)

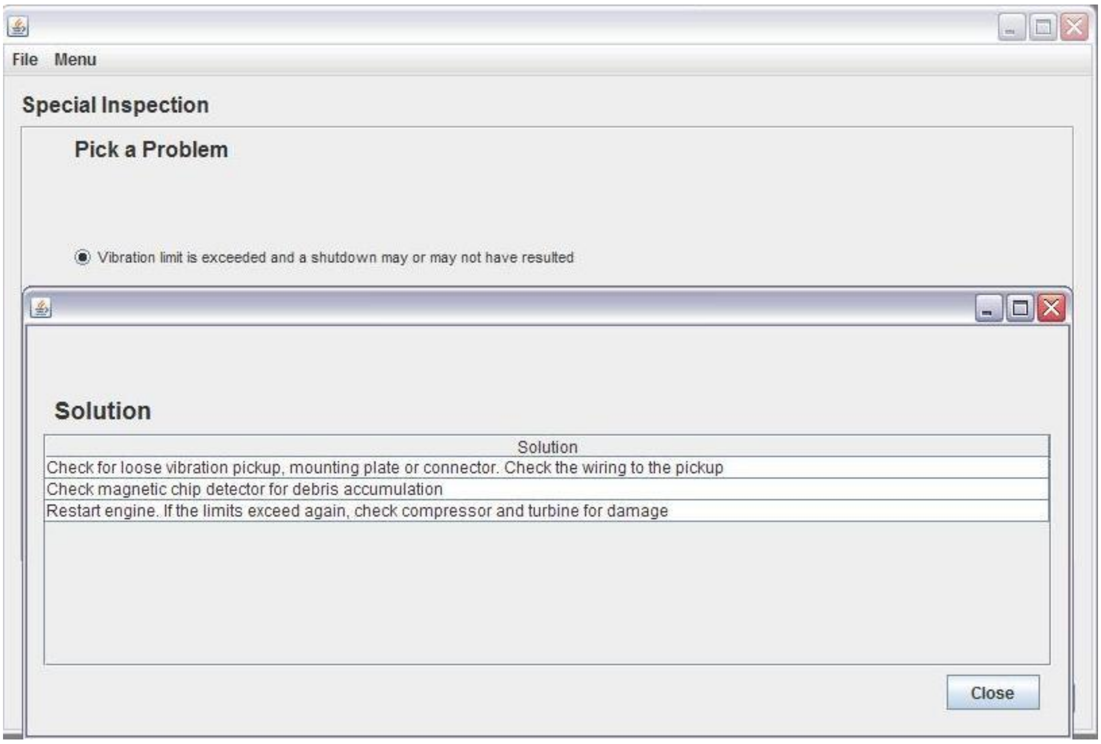
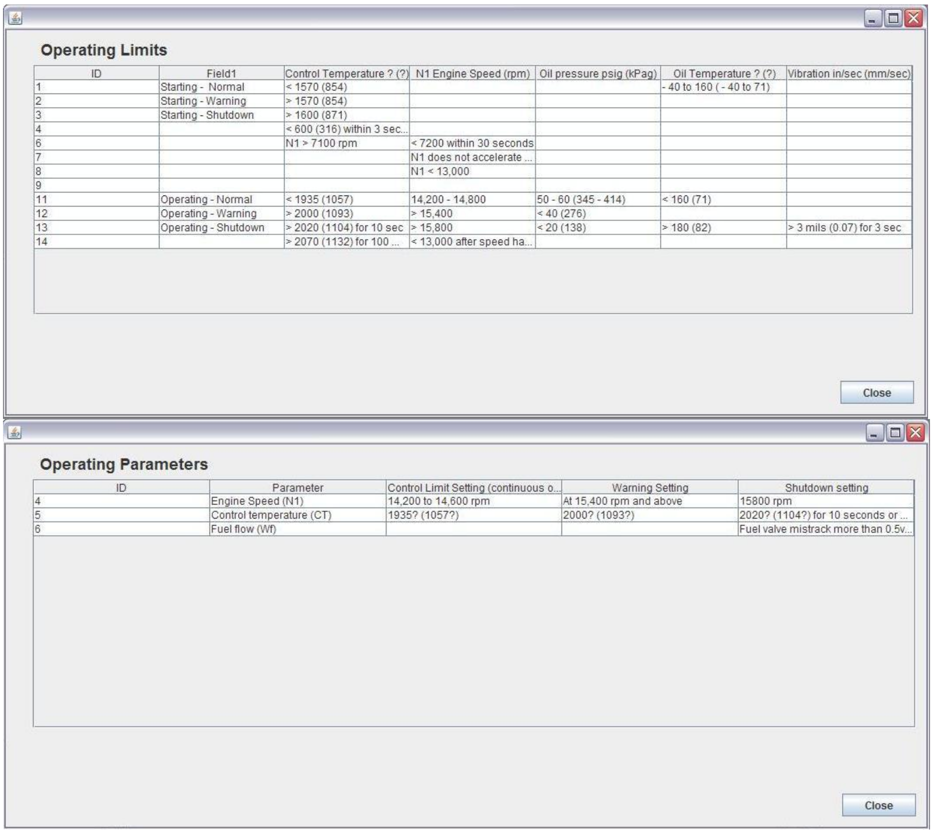


Figure 5.6: Troubleshooting (special inspection)

5.3 Reference Tables

Tables can be used during reconfiguration and stalled start problems.



Operating Limits

ID	Field1	Control Temperature ? (?)	N1 Engine Speed (rpm)	Oil pressure psig (kPag)	Oil Temperature ? (?)	Vibration in/sec (mm/sec)
1	Starting - Normal	< 1570 (854)			- 40 to 160 (- 40 to 71)	
2	Starting - Warning	> 1570 (854)				
3	Starting - Shutdown	> 1600 (871)				
4		< 600 (316) within 3 sec...				
6		N1 > 7100 rpm	< 7200 within 30 seconds			
7			N1 does not accelerate ...			
8			N1 < 13,000			
9						
11	Operating - Normal	< 1935 (1057)	14,200 - 14,800	50 - 60 (345 - 414)	< 160 (71)	
12	Operating - Warning	> 2000 (1093)	> 15,400	< 40 (276)		
13	Operating - Shutdown	> 2020 (1104) for 10 sec	> 15,800	< 20 (138)	> 180 (82)	> 3 mils (0.07) for 3 sec
14		> 2070 (1132) for 100 ...	< 13,000 after speed ha...			

Close

Operating Parameters

ID	Parameter	Control Limit Setting (continuous o...	Warning Setting	Shutdown setting
4	Engine Speed (N1)	14,200 to 14,600 rpm	At 15,400 rpm and above	15800 rpm
5	Control temperature (CT)	1935? (1057?)	2000? (1093?)	2020? (1104?) for 10 seconds or ...
6	Fuel flow (Wf)			Fuel valve mistrack more than 0.5v...

Close

Figure 5.7: Reference Tables

5.4 Scenario Notes

Scenario Note function is to record and store the information which is relevant and helpful for future reference. It is to use when there is a unexpected scenario or information not available in the system.

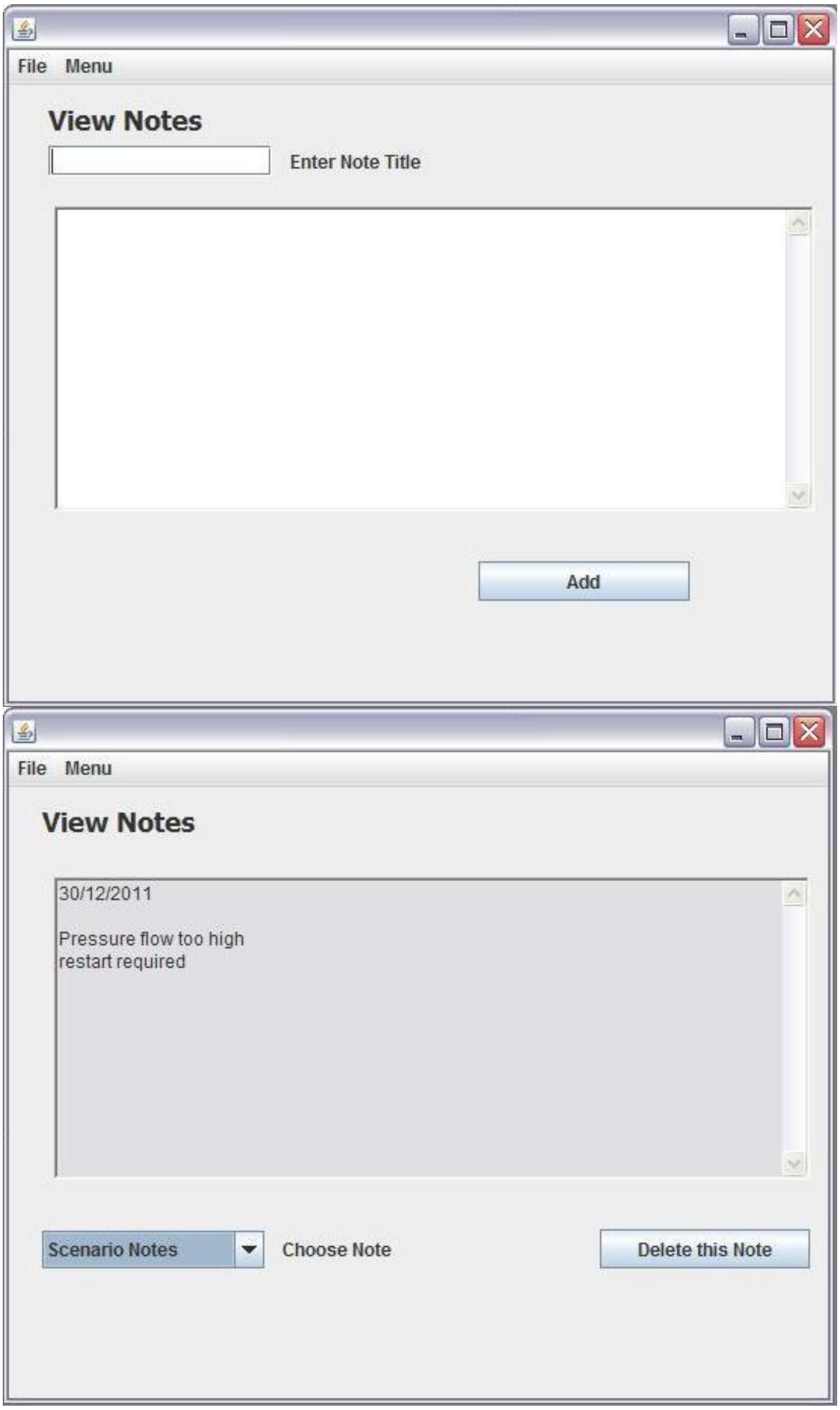


Figure 5.8: Adding & Viewing Scenario Notes

CHAPTER 6
CONCLUSIONS & RECOMMENDATIONS

Knowledge based Management system for rotating equipment diagnostic is to develop using the information from the troubleshooting manual provided by the suppliers and previous encountered problems to diagnose and solve the problem at hand. Industrial gas turbine (Rolls – Royce Allison 510 – KB7) is used as the emphasis of the project to develop the application. Case based Reasoning and Spiral Life Cycle model are used as the methodology in this project for the methods can support and fulfil the objectives of the project. Microsoft Access and Java runtime are used for the database set up and system development respectively. The final system offers eight different scenarios for gas turbine diagnostics. Reference tables and Scenario note function are included to aid and serve as future reference. The system is effective and less time consuming, platform (operating system) independent, easy to use and should be helpful for the maintenance engineers.

Diagnostics for the auxiliary system of the gas turbine should be incorporated in the system to have a more complete system. Auxiliary systems fails are more likely to happen then main components of the gas turbine. Due to the limited data and information, using Microsoft Access is efficient for the need to store and manage the information is relatively small amount. MySQL database system should be used in the future development if the database is to expand.

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APPENDIXES

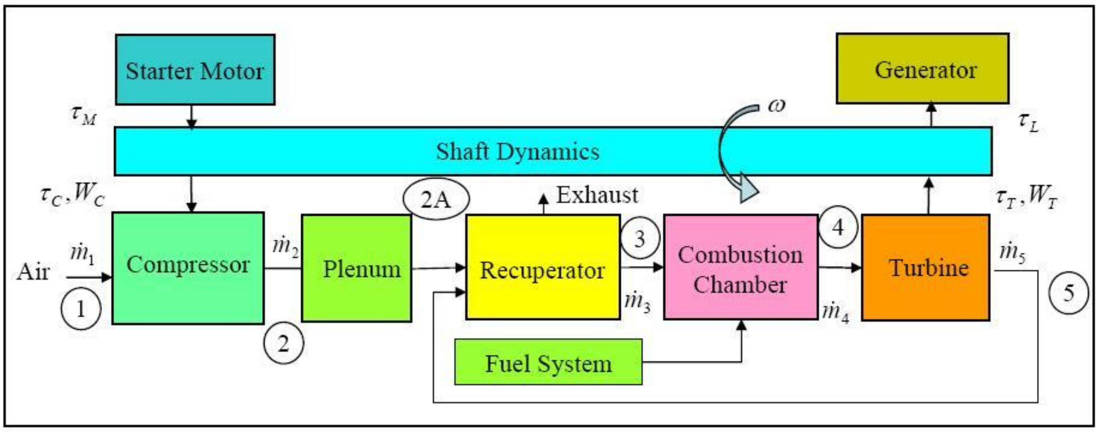


Figure A1:Gas Turbine operating process
http://www.ppienergygroup.com/msw-plant.html

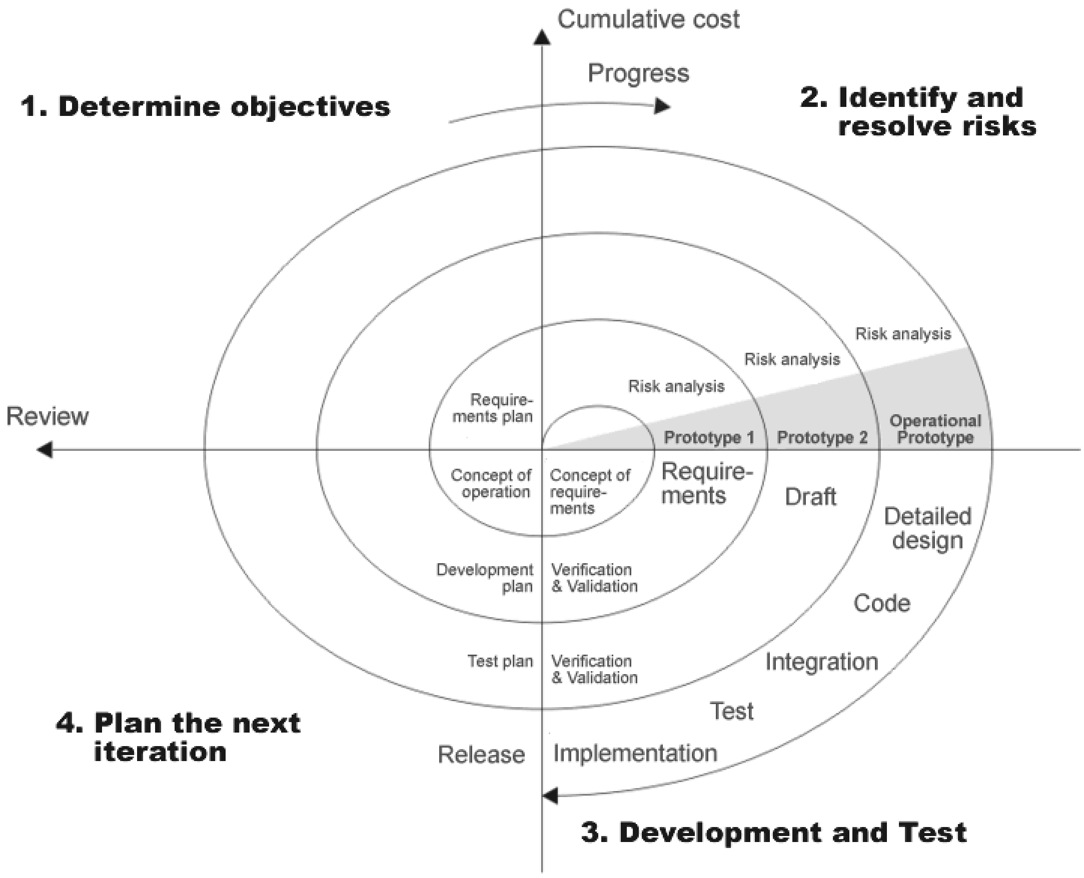


Figure A2 : Spiral Life Cycle model
http://www.jknichols.co.uk/SL2.html

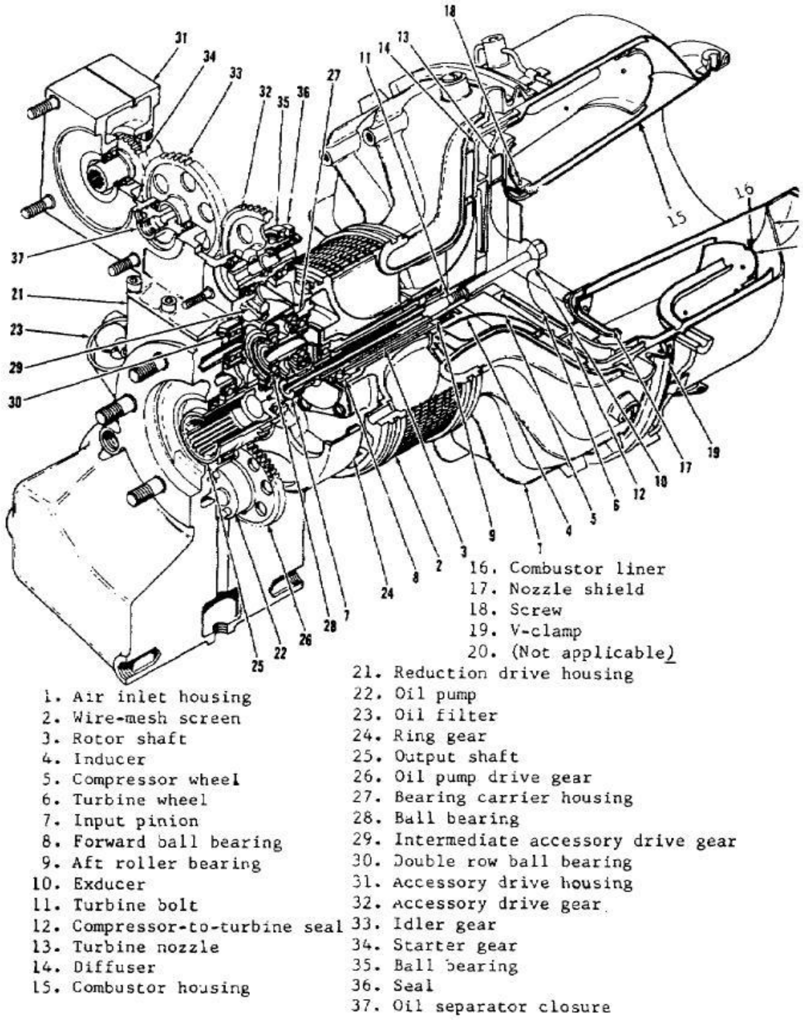
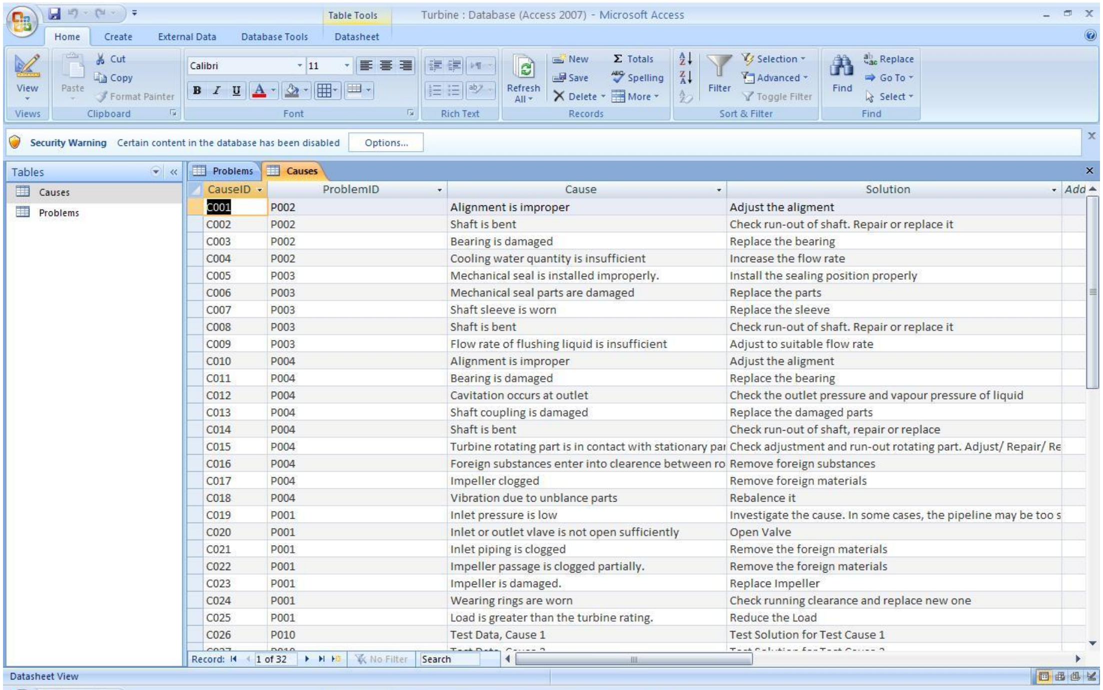
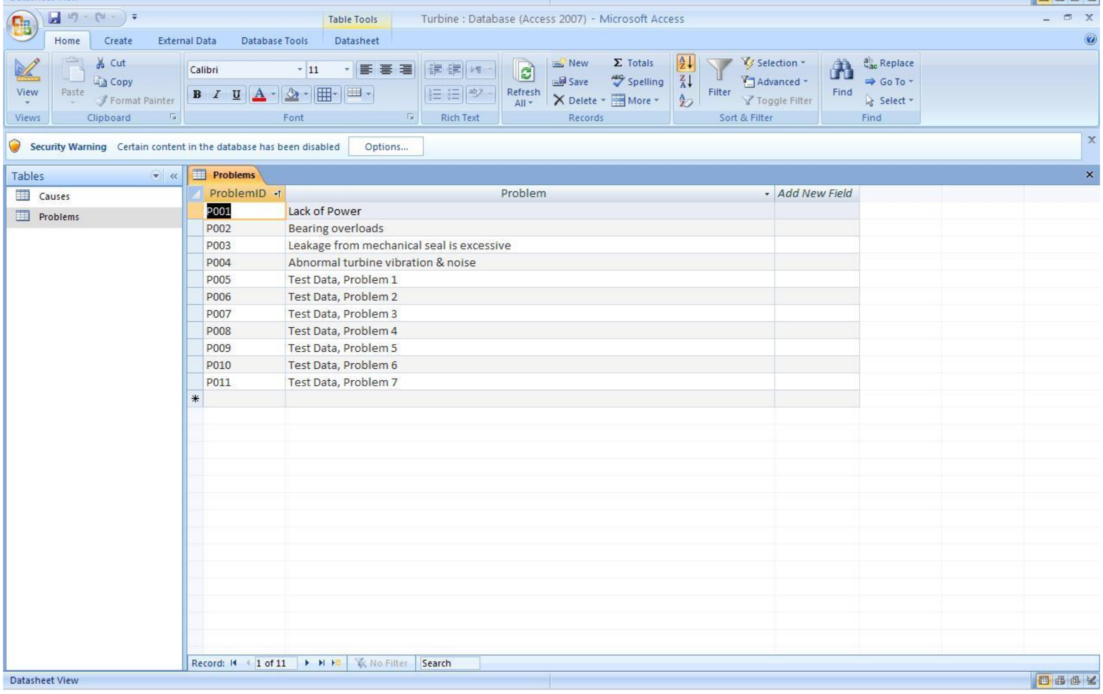


Figure A3 : Gas Turbine used in power generation
http://www.tpub.com/content/armyaviation/AL0993/AL09930329.htm



CauseID	ProblemID	Cause	Solution
C001	P002	Alignment is improper	Adjust the aligment
C002	P002	Shaft is bent	Check run-out of shaft. Repair or replace it
C003	P002	Bearing is damaged	Replace the bearing
C004	P002	Cooling water quantity is insufficient	Increase the flow rate
C005	P003	Mechanical seal is installed improperly.	Install the sealing position properly
C006	P003	Mechanical seal parts are damaged	Replace the parts
C007	P003	Shaft sleeve is worn	Replace the sleeve
C008	P003	Shaft is bent	Check run-out of shaft. Repair or replace it
C009	P003	Flow rate of flushing liquid is insufficient	Adjust to suitable flow rate
C010	P004	Alignment is improper	Adjust the aligment
C011	P004	Bearing is damaged	Replace the bearing
C012	P004	Cavitation occurs at outlet	Check the outlet pressure and vapour pressure of liquid
C013	P004	Shaft coupling is damaged	Replace the damaged parts
C014	P004	Shaft is bent	Check run-out of shaft, repair or replace
C015	P004	Turbine rotating part is in contact with stationary par	Check adjustment and run-out rotating part. Adjust/ Repair/ Re
C016	P004	Foreign substances enter into clearence between ro	Remove foreign substances
C017	P004	Impeller clogged	Remove foreign materials
C018	P004	Vibration due to unblance parts	Rebalence it
C019	P001	Inlet pressure is low	Investigate the cause. In some cases, the pipeline may be too s
C020	P001	Inlet or outlet vlave is not open sufficiently	Open Valve
C021	P001	Inlet piping is clogged	Remove the foreign materials
C022	P001	Impeller passage is clogged partially.	Remove the foreign materials
C023	P001	Impeller is damaged.	Replace Impeller
C024	P001	Wearing rings are worn	Check running clearance and replace new one
C025	P001	Load is greater than the turbine rating.	Reduce the Load
C026	P010	Test Data, Cause 1	Test Solution for Test Cause 1



ProblemID	Problem
P001	Lack of Power
P002	Bearing overloads
P003	Leakage from mechanical seal is excessive
P004	Abnormal turbine vibration & noise
P005	Test Data, Problem 1
P006	Test Data, Problem 2
P007	Test Data, Problem 3
P008	Test Data, Problem 4
P009	Test Data, Problem 5
P010	Test Data, Problem 6
P011	Test Data, Problem 7

Figure A4 : Database setup