The Insertion of Advanced Diagnostic Technologies in an Ageing Fleet of Engines, to Improve Engine/Aircraft Availability and Mission Reliability

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ABSTRACT

In any aging propulsion system, there is increasing potential for unanticipated problems which will require rectification, and such occurrences could influence cost and availability. This paper presents a case study of the way in which technology insertion into an engine – the PW TF30 engine in the F-111 aircraft, together with an active program to benefit from the insertion by the engine operator, can have a dramatic effect on engine support costs. When it became obvious that Australia would be the only operator of the F-111 in the world, following the decision by the USAF to retire its F-111 fleet earlier than originally planned, the RAAF started a concerted effort to shift TF30 engine maintenance from a fixed-time philosophy to a Condition Monitored Maintenance (CMM) policy. The CMM approach aimed to improve engine Reliability, Availability, and Maintainability (RAM). In support of this approach, and to facilitate its implementation, DSTO undertook the insertion of advanced diagnostic concepts and life assessment and extension technologies in an ageing fleet of engines, in order reduce the cost of ownership and to enable the aircraft to meet a planned withdrawal date that was conditional on external factors. This program has been outstandingly successful and provides a benchmark for managing all engines in the Australian Defence Force.

1.0 INTRODUCTION

The Pratt & Whitney TF30 engine was the first turbofan engine to be installed in a supersonic bomber, and the first turbofan to be fitted with an augmented afterburner, with development occurring as early as 1958. The engine is a two spool low by-pass turbofan with a mixed flow exhaust. The fan and low pressure compressor are driven by a 3 stage low pressure turbine, while the high pressure compressor is driven by a single stage high pressure turbine.

Early development problems were severe, with a major difficulty being that the design of the advanced compressor put the operating points too close to the stall line. Numerous versions were produced, of which the following remained operational the longest:

- TF30-P-3, P-103 in the F111C.
- TF30-P-7, P-107 FB111A.

- TF30-P-9, P-109 in the EF111A.
- TF30-P-108 in the RAAF F/RF-111C/G aircraft.

This latter version with afterburner was an improved long-life engine fitted to remaining RAAF F/RF-111C/G aircraft. By 2003 a number of problems were increasing the difficulty and cost of maintaining the 35 aircraft (of varied subtypes). The planned retirement date of the aircraft has varied over the last ten years to be between was 2010-20220, with a present figure of 2010. Although the main problems have centred on the airframe, rather than on the engine, studies were carried out to reduce the maintenance cost and to increase the reliability of the engine to a flexible withdrawal date that could extend to 2020.

Two Pratt and Whitney engines are installed in the F-111 aircraft, the TF30-P103 in the F-111C and the TF30-P107 in the F111G models. The prime advantage of a turbo-fan compared to a conventional turbo-jet engine is the low thrust specific fuel consumption (TSFC). TSFC is the mass of fuel used to produce one pound of thrust. The lower the TSFC the higher will be the engine efficiency. The TSFC is about 30% less for turo9-fans than for turbo-jets. Other advantages of the TF30 engine are the light weight, small size and reduced noise. At basic engine power (non-afterburner) the engine will produce thrust of approximately 10,000ponds. Conventional turbo-jet engines of this same thrust class require approximately 9,000 to 10,000 pounds per hour fuel flow, but the TF30 will consume only about 6,500 pounds per hour.

2.0 THE EARLY HISTORY OF F-111 AND DSTO INVOLVEMENT

Designed in the 1960's, the F-111 aircraft was manufactured by General Dynamics (now Lockheed Martin) in Fort Worth, Texas, throughout the late 60's and early 70's. Featuring variable sweep wings, the aircraft has the ability to operate low level, day or night, in all weather conditions, carrying a large payload over a long range, as well as being capable of speeds up to Mach 2.5. Some 562 aircraft were manufactured, covering several different models, and two main variants (short wing tactical strike and long wing strategic bomber). Some of the tactical strike aircraft were later converted to an electronic warfare model. Australia was the only country other than the USA to purchase the F-111.

The RAAF's initial purchase of 24 F-111C aircraft started operations in 1973 at Amberley air base in south-east Queensland. In 1982, the RAAF took delivery of 4 F-111A's to replace attrition aircraft. These F-111A models underwent significant modifications, which virtually upgraded them to F-111C configuration. In 1993/4, 15 F-111G's were introduced into RAAF service (although only about half of these were reinstated to flying condition). In recent years, a purchase of F-111D and F-111F (short) wing sets have also been introduced into the fleet, however these have had a wing tip extension added and hence will be flown in the RAAF's long wing configuration.

Australia is now the only operator of the F-111 in the world, following the decision by the USAF to retire its F-111 fleet earlier than originally planned. This decision was first announced in December 1994. The bulk of the USAF fleet was retired in 1996, and the remaining forty or so aircraft, which provided electronic warfare/radar jamming capabilities, were finally retired in June 1998. When the last EF-111A was withdrawn from service in the US fleet in1998, the RAAF became the only operator of the F-111 weapon system in the world. At this time the benefits of shared operation that the RAAF had enjoyed over the previous twenty four years disappeared and the sole responsibility for technical airworthiness of this weapon system fell upon the logistics system of the RAAF. The program that defined the way the platform was supported in this environment was dubbed the F-111 Aircraft Structural Integrity Sole Operator Program (FSOP).

The significance of USAF F-111 withdrawal must be fully appreciated with respect to RAAF structural integrity management of both the airframe and the engine. Sole responsibility for the F-111 ASIP and ESIP became the responsibility of the RAAF for what could be the next 22 years (almost half the life time of the aircraft). Up until then OEM support, shared responsibility with the USAF and relative low AFHRS of the fleet enabled airworthiness of both airframe and engine to be held at an acceptable level without large investments in structural integrity assessments. The objective of the FSOP was to develop a road map for the progression of the structural integrity management in such way that ongoing technical airworthiness was assured.

In anticipation of the USAF decision, an F-111 Supportability Study was carried out by RAAF in mid 1990's. This study considered the spares, data and capabilities needed for independent in-country support of RAAF F-111 fleet. The study concluded that the aircraft was supportable to a Planned Withdrawal Date of 2020. Several critical issues were identified and addressed by appropriate strategies. In addition, two major risk factors were identified:

- Engineering Risk Factor – Resulting from the loss of advance warning of potential technical problems from USAF fleet leaders, and the loss of the Original Equipment Manufacturer (OEM) support infrastructure and corporate memory.
- Ageing Aircraft Risk Factor – Associated with operating an aircraft beyond its original design life.

DSTO R&D Support was considered to represent an essential part of the Risk Management strategy for these risk factors. The study led to the F-111 support project to acquire the spares, data and capabilities.

DSTO identified the extra S&T effort required and the resources needed (across all aircraft systems and relevant divisions of DSTO). A bid for additional funding to DSTO for F-111 support was prepared and approved, providing $22m of additional funding, phased over 10 years. This funding is additional to the historical baseline of DSTO expenditure on F-111 support. Resources came as either special DSTO funds or external RAAF funds. A parallel study by the support activities for the engine identified the spares and maintenance requirements for the engine and endeavoured to contain engine maintenance costs. The extra resources for TF30 engines support work came through special DSTO funding.

For the TF30 engine, the need for a viable in-country capability to manage critical engine technical airworthiness issues, with less reliance on OEMs, received increased emphasis. This requires the ability to analyse and assess the service life of gas turbine engine components, including those subject to low-cycle, high-cycle and thermo-mechanical fatigue, creep, and thermal distress. This in turn requires the coordinated development of scientific capabilities and models for, mission profile analysis, engine gas paths analysis, thermal analysis, stress analysis, fracture mechanics and risk/reliability analysis. These are all complemented by appropriate experimental validation facilities. In addition there is a need to develop and support the implementation of life extension strategies for short-life components, with an emphasis on the engine hot section. In addition, an assessment is underway of retirement-for-cause methodologies for application to the management of critical components and, if appropriate, support will be provided for implementation of a retirement-for-cause program.

Concurrently and in consultation with DSTO, the Royal Australian Air Force (RAAF) decided to rationalise the number of TF30 variants to be maintained. To maintain reliable operation of the ageing F-111C fleet, the aircraft's Pratt and Whitney (P&W) TF30-P-103 engines were replaced with higher performance P&W TF30-P-109RA engines. This will result in a unique variant of the F-111 aircraft. A flight trial was conducted by the RAAF, with assistance from AOD and P&W, to characterise the change in performance of an F-111C aircraft installed with TF30-P-109RA engines. Traditional performance test techniques, dynamic manoeuvring and mathematical modelling were used to evaluate aircraft performance and airframe lift and drag characteristics. Lift and drag characteristics were verified with manufacturers data, permitting cruise and combat performance to be estimated using mathematical models of the airframe aerodynamics and installed engine performance. The F-111C/TF30-P-109 aircraft was approved for operational flying as a result of the trial.

DSTO participated in engine testing activities and with flight trials to determine the uninstalled and installed performance of the engine. Development of the P108 version TF30 engine was critical to enable use of the G-model airframe without the logistical costs associated with retaining the G-model's original P107 engines.

3.0 A GENERAL OVERVIEW OF DSTO ENGINE INVOLVEMENT

It has now been determined that there are no significant issues surrounding the logistics of TF30 engines and that sufficient spare parts and engines exist to see the fleet through to 2020. This is largely due to the successful program of reliability enhancement upgrades with new parts and surplus later model USAF engines, and other initiatives with DSTO involvement. Further DSTO involvement has been aimed at reducing the maintenance activities on the TF30 engine to reduce the overall maintenance cost as a proportion of the total system cost.

Currently the TF30 has a fixed scheduled servicing program with Bay Service (BS) maintenance occurring every 800 ENHRS and Overhaul (OH) every 1500 ENHRS. Several years ago DSTO was asked to develop strategies to increase the overhaul period of the engine from 800 hours to 1200 hours. Without this extension the RAAF would not have been able to guarantee engine asset availability through to the then planned withdrawal date of 2020. Investigations showed that the component that largely determined the overhaul period was the combustor liner. Three strategies were investigated to increase the life of the combustor. These were:

- The use of a thermal barrier coating (TBC) to reduce metal temperatures;
- Structural modifications to the combustor liner; and
- The use of a thermal additive in the fuel.

The first and second of these strategies are now used on all of the TF30 RA engines and it is expected that Amberley will convert to the additive once concerns over fuel tank sealant compatibility issues are allayed in the near future. AVD completed laboratory and TF30 engine trials to prove the effectiveness of the +100 additive, which, when implemented by RAAF, can be expected to reduce coking/fouling of fuel nozzles that results in hot streaks in the combustor. These hot gas flows result in significant thermal damage to hot section components, and hence the use of the JP8+100 fuel will reduce engine maintenance costs.

DSTO has developed advanced vibration, gas-path and oil condition diagnostic techniques which in part are responsible for a decrease in the cost of engine maintenance, and an improvement in engine reliability.

DSTO has provided airworthiness advice on cracks and metallurgical flaws found in critical rotating engine components. Particular examples are the fan disc balance weight cracking and fan disc tie bolthole cracking. DSTO-AVD advice was crucial in lifting the suspension of flying operations on the fleet. DSTO has also been involved in analysis of F-111 usage for verifying the lives of safety-critical components.

4.0 RAAF FLEET SUSTAINMENT

Since the mid 1990's the RAAF F-111 fleet time indicators in maintenance, availability and cost took a turn for the worse. There were many coincident contributors: fuel leaks, OH&S issues, block upgrades, fleet wing doubler failure and WOM development, support project activity, contracting out of maintenance, and finally the wing recovery program and the increasing cost of maintaining an ageing engine.

At present there is no indicator from either the airframe or engines of specific issues that would cause support costs to escalate. On the engines side, developments like the maintenance interval extension of the RA engine and the improved software for the engine test-cells will likewise reduce support costs. The engine diagnostic software has, in part, resulted in engines staying on wing longer due to optimum trimming of the fuel controls, and also provides improved diagnostic information prior to maintenance, avoiding unnecessary repairs. These activities, together with the engine Reliability, Availability, Maintainability (RAM) program developed by the TF30 Engine Business Unit (EBU), have resulted in significant improvements in engine reliability and reduction in maintenance costs. As an example, in-flight shutdowns have decreased from 5 to 0.3 per year, while costs have decreased form $30 million per year (prior to 1990), to $20 million per year.

5.0 TF30 P-109RA ENGINE BASELINE CONFIGURATION

The modification was raised to record the configuration change of ex USAF TF30-P-109 to TF30 P-109RA after the incorporation of a series of reliability type modifications during overhaul. The RAAF's P-103 engine has become unsupportable and ex USAF P-109 engines were acquired as Excess Defence Articles from the US DoD. A P-109 Engine Upgrade Project was established in 1995, to replace P-103 engines with ex USAF P-109 engines that pass an Induction Servicing and P-109 engines that have undergone overhaul to the P-109RA configuration. This modification ensured that particular technical build improvements were incorporated during overhaul to optimise engine reliability and reduce cost of ownership. Hence, the 'RA' suffix is be used to designate overhauled P-109 engines built to the RAAF unique configuration defined in this modification.

The modification incorporated twenty two technical build improvements as well as applicable P-103 modifications deemed necessary for the P-109RA engine. P-109RA engines will have a serial number structure of 'P99-XX'.

The modification was aimed at improving the reliability of the P-109 baseline configuration such that the Bay Service and Overhaul scheduled maintenance intervals can be extended safely, to minimise TF30 Life Cycle Cost. A Maintenance Requirement Determination (MRD) will be carried out to determine an acceptable extension to scheduled servicings based on advice from the OEM and the results of a RAAF TF30 Fleet Leader Program (FLP).

The listed modifications involved:

- A proposal for the introduction of a TF30 Engine Monitoring System, primarily to determine the TF30 Engine Usage and to enable analysis of the engine mission for all TF30 variants, and in addition to provide some capability for condition assessment of individual engines;
- A proposal to assess the durability of specific critical engine items through an Accelerated Mission Test (AMT) using a simulated RAAF mission;
- A firm proposal to increase the bay service life of TF30 hot section components from 800 hours to 1000 hours and the overhaul lives from 1500 hours to 2000 hours using durability enhancements such as thermal barrier coatings; and

- A proposal to implement a fleet leader program for the engine which will identify failure modes in the fleet leader engine before they occur in the fleet.

6.0 DSTO INVOLVEMENT

In the early 1990's the RAAF started a concerted effort to shift TF30 engine maintenance from a fixed-time philosophy to a Condition Monitored Maintenance (CMM) policy [1]. The CMM approach aimed to improve engine Reliability, Availability, and Maintainability (RAM). In support of this approach, and to facilitate its implementation, DSTO undertook the development of a number of diagnostic systems for the TF30 gas turbine engine. Different diagnostic systems were required as the gas turbine is a complex mechanical system and no single technology or methodology can provide all the answers.

In this paper, three diagnostic systems are described. These are: the Engine Diagnostic and Acceptance System (EDAS) for troubleshooting and acceptance testing at the test-cell; a set of advanced Gas Path Analysis (GPA) methods for diagnosing faults to a modular level at the test-cell; and the Interactive Fault Diagnosis and Isolation System (IFDIS) for troubleshooting engine faults at the flight line.

7.0 DIAGNOSTIC REQUIREMENT

There is demonstrable benefit in terms of cost-efficiency of the repair and overhaul process in having a capability to correctly identify and isolate the faults in the TF30 engine to a modular level. The six TF30 modules are: the fan, the low and high pressure compressors, the low and high pressure turbines, and the nozzle. Correctly attributing the fault to the right module can bring about major cost savings and improved engine availability [2,3]. These benefits are demonstrated by the relative cost and time involved in repairing the TF30 modules. The typical cost and time impact of a compressor module repair is twelve times that of a fan module repair and a turbine module repair is four times that of a fan module repair. Clearly, for the TF30 engine, the major benefits arise from correctly attributing the fault to either the fan or a turbine module in preference to a compressor module; or in other words, from not falsely attributing the fault to a compressor module.

The correct diagnosis of TF30 faults requires the application of a number of different technologies and methodologies. These include the use of fibre-optic Bore-Scopes, Oil Debris and Condition Monitoring, Vibration Analysis, Gas Path Analysis, and fault-tree troubleshooting of engine controls and accessories by Artificial Intelligence. Indeed, there is little overlap in the type of faults diagnosed by these techniques; each has its own niche. This is illustrated in Figure 1 where the causes of unscheduled maintenance are matched to appropriate diagnostic techniques. DSTO's program of work on conditioning monitoring is addressing most of these techniques, including Vibration Analysis [4], but only the progress on diagnosing gas path faults and troubleshooting control and accessory faults is reported here.

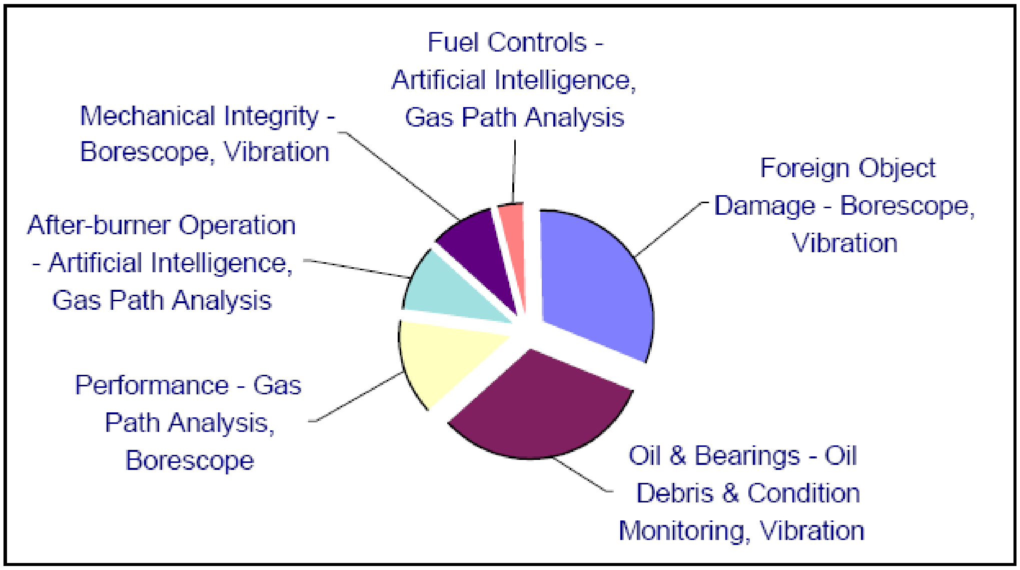

Figure 1: Causes of unscheduled maintenance and appropriate diagnostic techniques.

8.0 ENGINE ACCEPTANCE TESTING USING EDAS

In the mid-1990's, the RAAF sought to refurbish and modernise the engine test-cells at RAAF Amberley. In response to this requirement, DSTO developed an affordable PC based system for the repair and overhaul testing of the TF30 engine. Called the Engine Diagnostic and Acceptance Test System (EDAS) [5], it was installed in Engine Test Cell 2 in June 1996 and then in Engine Test Cell 1 in November 1997. Over the past four years, EDAS has been in day-to-day operation with the RAAF, supported by industry. Overall, EDAS has improved the efficiency of the test acceptance process and produced major cost savings.

EDAS is a Windows-based program written in Microsoft Visual Basic [6,7]. It operates on two separate PCs, with one PC in Engine Operator mode and the other in Test Analyst mode. Both PCs acquire a standard suite of 39 test parameters at 32 Hz. In the Engine Operator mode, EDAS ensures the safe operation of the TF30 engine by displaying to the operator all the test parameters on one PC Monitor. Hence, with this one PC screen, EDAS has replaced all the old gauges and eliminated the need to support them. In the Test Analyst mode, the EDAS menu guides the analyst through the acceptance test schedule with EDAS performing the required calculations, displaying the results on the PC screen and sending the accepted test values to an Excel Spreadsheet for reporting on and archiving the results of the test runs. This PC menu based process has reduced the time to test engines by almost a half.

The current configuration of EDAS provides a basic diagnostic capability in terms of functional checks and troubleshooting. As well, EDAS has enabled the comparison of engine performance between Engine Test Cells 1 and 2 as a result of the improved accuracy of the recorded parameters. Previously, this comparison was not viable due to the uncertainty in the manually recorded data. In 1998, a program was undertaken to enhance the diagnostic capability of EDAS by developing a range of advanced Gas Path Analysis techniques to address the problem of diagnosing engine condition to modular level. EDAS provides the major prerequisite for the use of such techniques – accurate measurements of the engine gas path parameters.

9.0 MODULAR DIAGNOSTICS USING GAS PATH ANALYSIS

Gas Path Analysis (GPA) serves a different role to the other main Health Monitoring Technologies of Vibration Analysis (VA) and Oil Condition Monitoring (OCM). VA and OCM attempt to diagnose events that lead to a catastrophic failure of an engine component, and so they have a safety or airworthiness impact. Whereas, GPA attempts to diagnose events that lead to a more graceful degradation in the function of the engine, and so it has a performance or mission-worthiness impact.

Gas Path Analysis (GPA) seeks to diagnose the loss of engine condition due to causes such as: eroded, corroded and fouled blades and vanes; tip clearance changes, turbine blade untwist and bowed vanes; bleed and air-seal leaks, mis-scheduled variable geometry, control system failures and sensor failures. GPA seeks to infer the condition of the engine's gas path from the changes in the engine's thermodynamic parameters, i.e. the measured pressures, temperatures, speeds, torque, air and fuel flows, from their reference or healthy values [8,9]. Traditionally, GPA uses engine models to generate the reference values and influence coefficients. The influence coefficients provide the fault information as they represent the effect of a change in a given component variable, such as a 1% decrease in fan efficiency, on the change in the measured engine parameters.

Pioneered in the early 1970's, the GPA methodology has found some limited success in the engine test facilities of civilian airline operators [10-12]. However, the typical aero-engine application presents a number of difficulties for GPA that must be overcome before it can become a more effective diagnostic tool. Indeed, the current methods still fall short of what can be achieved by a skilled analyst [13].

The first difficulty is that GPA must work with the very limited set of gas path instrumentation, both in terms of number and location, provided on production engines. The typical set is a long way from the ideal set of pressures and temperatures at the inlet and outlet to each component. Consequently, the problem of fault observability and uniqueness arises as a number of fault scenarios may fit the observed symptoms – the measured parameters.

The second difficulty is that GPA uses model-based influence coefficients that are deterministic whereas the actual process is stochastic. Consequently, the methodology needs to be modified so it can correctly isolate faults against the observed measurement and model uncertainty.

The third difficulty is that the influence coefficient approach assumes that the component variables such as efficiency and mass flow are independent whereas in reality they are coupled with the actual coupling being related to the type of fault, such as tip clearance changes. Incorporating this information within the methodology helps the diagnosis by restricting the domain of possible faults.

The fourth difficulty is that GPA must diagnose the occurrence of multiple component faults as the engine is likely to suffer some degradation through several modules. So far the success of the influence coefficient approach has been restricted to cases where single faults are present. Consequently, the methodology needs to be improved so it can recognise the occurrence and severity of multiple faults.

The fifth difficulty is the almost complete lack of specific and validated fault signatures for the engines – the problem that we are trying to diagnose. Whilst the general literature, model studies and fault implant tests provide some guide as to the likely fault signatures, they are not specific enough to be of practical use when diagnosing the faults of a given engine. Consequently, an important step is the development of a fault library that summarises the repairs that are performance related and their frequency of occurrence, and provides the link between the cause (the mechanical condition) and the symptoms (the gas path performance). However, as the process for collecting this information is not in place, it must be introduced.

In seeking to address the above weaknesses in the traditional GPA methodology, and so provide a more practical and robust diagnostic method, a number of different diagnostic tools have been developed. These are illustrated in the flow chart of Figure 2 and they are described in more detail in the following three sections.

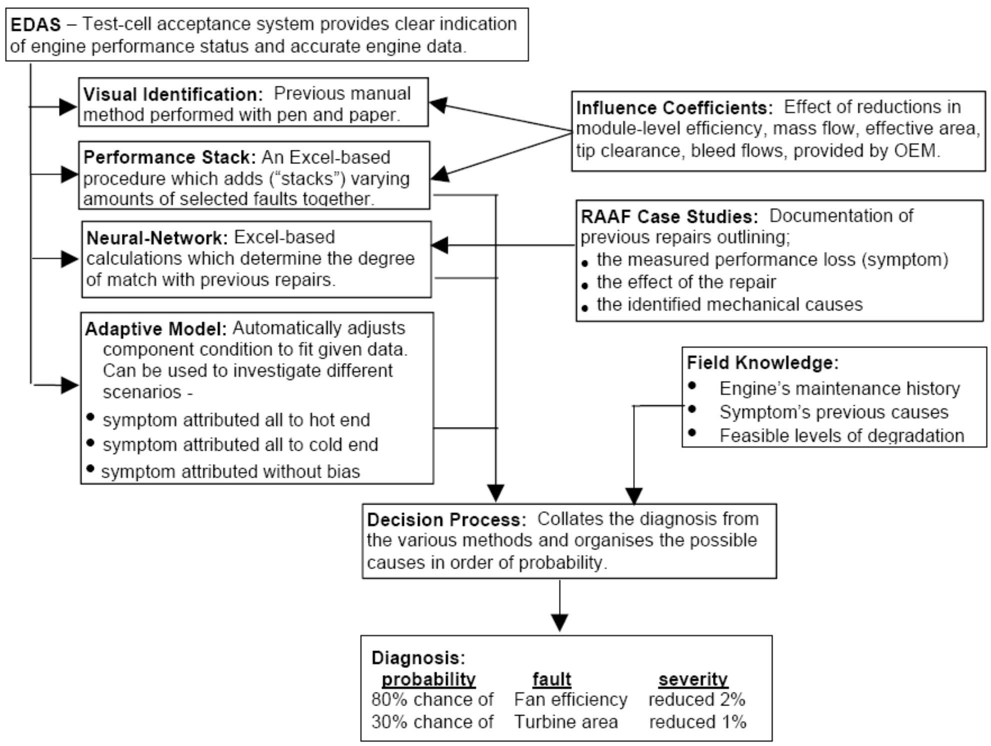

Figure 2: Gas-path diagnostic methods and process developed by DSTO.

9.1 Performance "Stack" of Fault Signatures

The RAAF had attempted the diagnosis of gas path faults using the unofficial Pratt and Whitney TF30 test-cell troubleshooting guide. This guide provides a set of influence coefficients covering the impact of 32 separate component malfunctions or deficiencies on six measurable gas path parameters. Whilst these P&W fault signatures contain valuable information and help the identification of dominant faults, the manual process of trying to visually identify multiple faults of near equal severity using single fault patterns proved impractical.

Initially, DSTO tried a fully automated approach to recognising the P&W fault signatures using neural networks. Whilst it easily identified the occurrence of single faults and showed an ability to identify those multiple faults that affected different sets of parameters, it struggled to identify multiple faults when the fault signatures overlapped. As a result of the weaknesses of both the manual and fully automated approaches a semi-automatic method was developed.

Selected Fault:	Severity,%	N1	N2	TIT	P3/P2	P4/P2	Wf
Nozzle area	+ 1.7	1.67	0.77	1.55	0.34	0.57	1.45
HPC efficiency	- 1.3	-0.09	-1.05	0.18	0.49	0.00	0.00
LPC airflow	- 1.1	0.02	0.09	0.25	-0.25	-0.15	0.06
HPC airflow	- 1.0	-0.02	0.60	0.09	0.13	0.00	0.00
Burner pressure loss	+ 0.7	-0.04	-0.34	0.10	0.21	0.21	0.04
LPC efficiency	- 0.5	-0.09	0.08	0.18	-0.01	0.00	0.08
HPT area	+ 0.4	-0.04	-0.40	0.00	0.20	-0.04	0.04
1st turbine cooling leak	+ 0.4	-0.02	-0.15	-0.07	0.05	-0.12	0.00
Total effect of selected faults:		1.38	-0.39	2.27	1.15	0.47	1.65
Observed performance loss:		1.30	-0.37	2.41	1.15	0.40	0.50
Un-accounted for loss:		0.08	-0.02	-0.14	0.00	0.07	1.15

Influence coefficients, adjusted to show the effect of the selected fault at the selected severity.

Sum of the effects of all the faults.

Symptom of engine being diagnosed.

Remaining symptom.

Figure 3: Performance Stack diagnosis of engine P103-8841.

This semi-automatic method allows the analyst to progressively stack up a fault scenario until the selected scenario accounts for the observed performance loss (symptom). The method uses the P&W influence coefficients to attribute the performance loss to specific faults as selected from a total set of 21 faults. The method is implemented as an Excel interface where the user selects and inputs a likely fault and its severity. The program then calculates the fault signature at the chosen severity, and subtracts this from the observed symptom, to give the portion of the symptom still to be accounted for. The user then selects another fault at a chosen severity and the process is repeated until the symptom has been accounted for. This method allows the analyst to use past maintenance history and expert judgement to guide the diagnostic process whilst still producing a thermodynamically consistent set of faults. As well, the analyst can try various what-if scenarios to include or exclude other fault possibilities. Importantly, on trial against RAAF test-cell data, this method has demonstrated a capability to diagnose multiple faults.

9.2 Probabilistic Neural Network with Case Studies of RAAF Repairs

In this second GPA method, an automated approach to fault diagnosis has been developed through the combination of a Probabilistic Neural Network (PNN) with the “case studies” of previous TF30 engine repairs. The fault diagnosis is based on how closely the engine being investigated matches previous repairs. This method has evolved from earlier DSTO studies into neural networks that demonstrated their ability to diagnose implanted faults in a single test-cell engine [14] and within the engine-to-engine build variations of a fleet of engines where the effect of a fault can be obscured by these variations [15]. The PNN presented here extends this work to diagnosing real-world faults within a fleet of military turbofan engines.

The PNN provides a mathematical method that is equivalent to the test-cell operator who can say “I know what is wrong with this engine because it has been seen before.” In comparison, the traditional gas path approach using influence coefficients does not know anything about the frequency or appearance of common symptoms that represent combined faults. They cannot make use of this operational knowledge and known diagnostic information. With every repair, the neural network has another example of an observed fault added to its knowledge base. In comparison, the traditional influence coefficient approach starts every diagnosis as if it is the first; it has no knowledge of past experience.

Case studies, which document previous repairs, form the important database of operational-knowledge for the PNN’s diagnosis. Whilst traditional scientific reports often provide a useful insight into the causes and effects of gas-path degradation, they usually do not provide measurements which are both practical and applicable to a specific engine. Hence, to establish a link between the cause and the symptom, a number of TF30 repairs were studied and a report format was developed to provide the RAAF with details of their own repairs. These case studies identify: the symptom using the parameters measured in the TF30 test-cells; the predicted degraded modules using the current diagnostic methods; the actual mechanical causes listed in the engine strip-down condition reports; the repair performed; and the performance recovered. Over time, these case studies will be built up into an invaluable fault database.

Each case study of a previous repair provides two links between the performance measurements and the mechanical condition (Fig. 4). The first link is between the performance loss (symptom) and the defects found when the engine is stripped. This link is often an approximation, since not all modules are repaired during unscheduled maintenance, allowing some defects to remain undiscovered. In addition the symptom can be inaccurate, as reliable no-fault data for the particular engine can often be hard to establish due to the passage of time since its post-overhaul test. The second link is given between the performance recovery and the repair work performed. This link is more accurate because it is clearly known what repairs were done, and the performance they recovered. Since some modules remain unserviced, the performance recovery cannot be expected to be exactly equal and opposite to the performance loss.

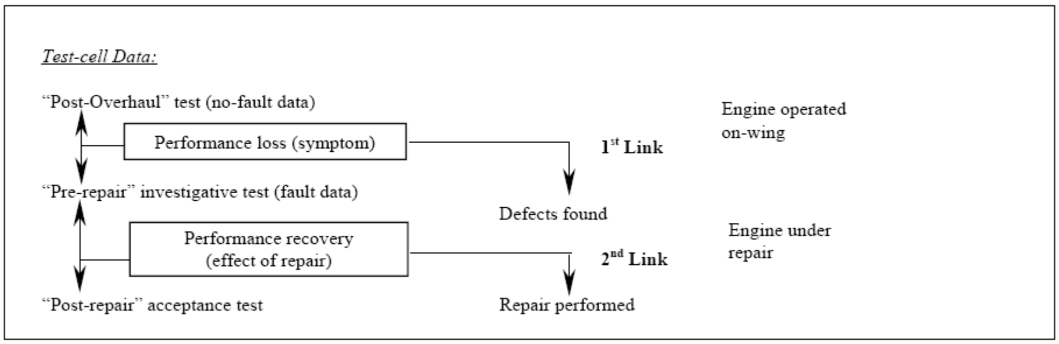

Figure 4: Links between observed performance and mechanical condition.

Our only clues to the condition of the engine being investigated come from its loss in performance compared to its own earlier no-fault condition. The PNN [16] calculates a statistical degree of match between this current symptom of the engine in-question and examples of previous repairs. This symptom being diagnosed is compared by the PNN with both a) previous symptoms, and b) previous performance recoveries. This first comparison is necessary, despite the inaccuracy of previous symptoms, because it is only fair to compare two like items with the same inherent process uncertainties. However, we also want to make use of the more accurate knowledge from the effects of previous repairs, so the second comparison is also performed.

The PNN is coded in Excel and its interface is shown in Figure 5. The symptom of the engine being diagnosed is entered in the top row. The symptom is measured between the pre-repair data and the engine's own post-overhaul data. The difference in seven parameters, at the same value of engine pressure ratio, is calculated. The symptoms and repair effects of the known case studies are contained vertically below the unknown symptom. For each case, the PNN calculates the degree of match, as shown graphically and by the % figure. The PNN can calculate the degree of match even if some of the seven input symptom-deltas are missing. This enables the effect that each parameter has on the degree of matching to be explored.

RAAF previous repairs		unknown	N1	N2	TIT	P3/P2	P4/P3	P4/P2	Wf	match
			rpm	rpm	deg F	------ psia / psia		-------	lb/hr	
case	serial	symptom:	10	300		-0.20	0.10	-0.35		%
1	5561	symptom	0	285	38	-0.16	0.04	-0.42	92	51
		repair	-41	-125	-44	0.00	-0.03	-0.13	95	0
2	5640	symptom	-19	190	8	-0.04	-0.21	-0.67	-133	0
		repair	19	-13	6	-0.03	0.08	0.26	120	0
3	8841	symptom	130	-45	53	0.19	-0.13	0.16	31	0
		repair	-143	20	-39	-0.26	0.16	-0.20	-35	0
4	4993	symptom	7	328	30	-0.29	0.20	-0.30	-221	13
		repair	-14	-96	8	0.07	-0.05	0.05	340	0

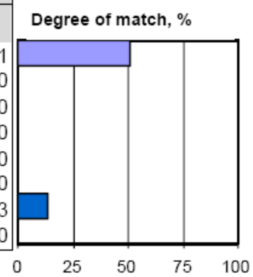

Figure 5: Diagnostic comparison of a symptom to 4 previous repairs.

This PNN approach closely follows the human identification process of using observed examples and it is capable of encapsulating information such as the frequency and appearance of symptoms observed in the test-cells. Such information is generally not used by traditional diagnostic approaches. The PNN is currently on trial with the RAAF.

9.3 Adaptive Model Approach

In this third GPA method, a robust adaptive approach to fault diagnosis has been developed based on the use of an adaptive component-based thermodynamic model of the TF30 engine [17]. Adaptive engine models [18] operate in reverse to a normal model. Typically, an engine model is run by selecting an input such as power lever angle and the model then computes engine speeds, pressures and temperatures. The adaptive model operates in the opposite direction. A schematic diagram of the adaptive modelling process is shown in Figure 6. The user inputs the engine measurements, and the model adjusts or 'adapts' its internal operation to achieve the requested values. If the engine measurements have been obtained from a degraded engine, then the way the model has had to adjust itself to obtain the degraded performance indicates how the real engine may also have degraded. Hence, the adjustments made by the adaptive model give a diagnosis of the engine's condition.

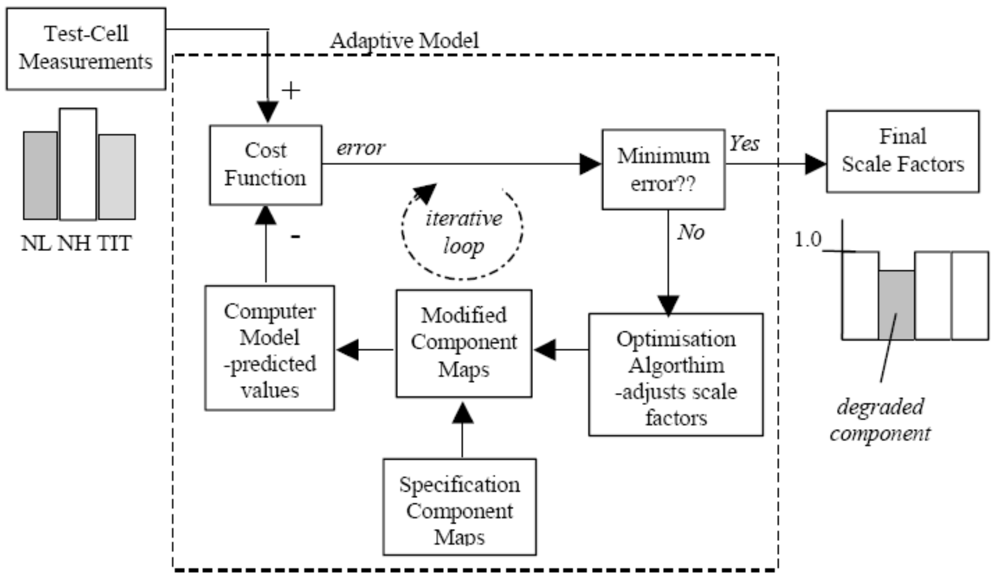

Figure 6: Procedure to calculate Scale Factors in adaptive modelling.

The adjustments made in the adaptive model to fit the given data are indicated by Scale Factors. A Scale Factor is simply a modification factor that is applied to a performance parameter, such as efficiency, mass flow or effective area of the engine's major components, such as the fan, compressor, or turbine. The Scale Factors model the effective change (or degradation) in the performance of the gas path components. They represent the difference between the degraded engine's performance and the computer model's reference performance. In theory, the Scale Factors equal one in a healthy engine and both increases and decreases from one indicate degradation. In practice however, Scale Factors will vary from unity even in undegraded engines due to modelling error, measurement noise and /or the normal variations in engine build.

The adaptive procedure uses the Downhill Simplex Method of Nelder & Mead [19] to solve for the unknown set of Scale Factors by stepping around the multi-dimensional surface of a Cost Function in search of the minimum value. A number of other optimisation algorithms were investigated and the Downhill Simplex method proved to be the best with respect to identification, time and simplicity. In a series of deterministic model-based studies, the adaptive model demonstrated the ability to correctly identify the simulated degradation in 100% of the cases where a single Scale Factor was degraded reducing to 80% for the cases where two, three and four Scale Factors were degraded. The failure to correctly diagnose the degradation was primarily due to the adaptive model finding multiple solutions – different degradation scenarios – that all fitted the degraded data equally well. Furthermore, in many of these multiple Scale Factor cases the simulated degradation was not the solution with the lowest Cost Function value. For this reason, the overall process retains and considers all solutions with low or acceptable Cost Function values, often 50 to 100, rather than just the solution with the lowest value.

However, the above basic adaptive modelling process was not sufficient by itself to provide a robust and effective tool for diagnosing engine faults in the presence of real world uncertainties. These uncertainties can be classified as arising from either modelling errors or sensor errors. Consequently, to handle such uncertainties in the TF30 test-cells, the adaptive modelling process was modified as illustrated in Figure 7.

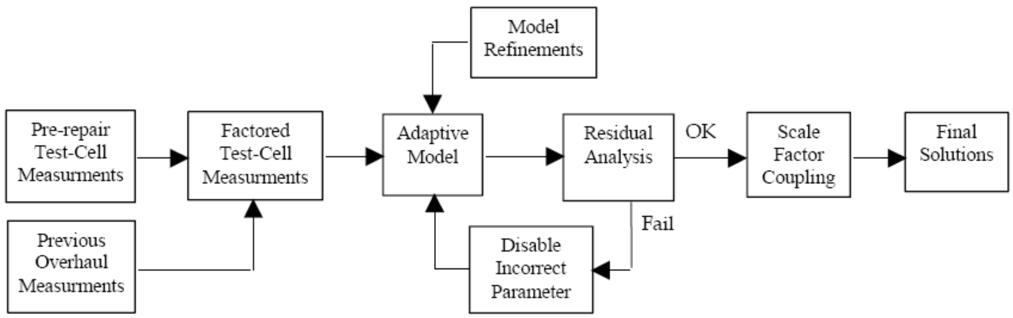

Figure 7: Adaptive Model approach for test-cell data.

The first step in this overall adaptive approach is the use of a "factoring" process to account for modelling error – the difference between the reference TF30 engine model and the no-fault "healthy" state of the engine under test. The "no-fault" or "baseline" value of each engine will vary across the fleet due to normal build differences and prior maintenance history. This engine to engine variation cannot be accounted for by a single "specification" reference model and if ignored would tend to hide the actual in-service degradation. This problem is partly addressed by using the post-overhaul data for each engine as the preferred baseline for determining in-service degradation. In the absence of post-overhaul data for a given engine, the average performance of post-overhauled engines must be used. The "specification" baseline is not used as this may indicate degradation that is unpractical or uneconomic to recover. The adjustment factors are calculated by dividing the model reference value by the engine's no-fault value. If the model and engine matched exactly, the factor would equal one. The engine's test data is then multiplied by these factors to provide the input to the adaptive model. Usually, the modelling error is removed after the adaptive process whereas here it is removed prior to the adaptive process.

The adaptive model was also modified to improve its performance. The changes included: (1) specifying an appropriate domain for the Scale Factors to constrain the region of the Cost Function surface where a solution was allowed; (2) introducing a weighting factor on the engine parameters in the Cost Function so as to reduce the impact of inaccurate sensors and to ensure that the optimisation algorithm continues to try and match the more accurate sensors down to a very small error; and (3) introducing a two stage optimisation strategy where the insensitive Scale Factors from the first stage are disabled making the second stage optimisation a much simpler task.

The next step after the adaptive model calculates the set of possible Scale Factor solutions is a Residual Analysis of the errors between the engine parameter values predicted by a given Scale Factor solution and the measured values. This is done in two parts. The first residual analysis looks for evidence of an individual sensor fault as indicated by a very high error in that sensor for all Scale Factor solutions. If this is the case, this sensor is rejected and the adaptive modelling is repeated but with out this sensor. The second residual analysis looks for evidence of bad Scale Factor solutions as indicated by the predicted values for a given parameter being outside the test-cell test to test variation of the measured parameters. If this is the case the solution is rejected. Neither of these methods is intended to detect small errors.

A key last step in the method is the use of a constraint on the plausible Scale Factor domain to reduce the 50 to 100 possible solutions generated by the adaptive model to a very small number of plausible scenarios of component degradation, say 2 or 3. In traditional GPA, the characteristic parameters of the component maps, such as efficiency and mass flow are treated as being independent of each other. However, most realistic gas path faults, such as eroded compressor blade tips, will affect both the efficiency and mass flow simultaneously. The allowable Scale Factor Coupling domain for the compressors is illustrated in Figure 8.

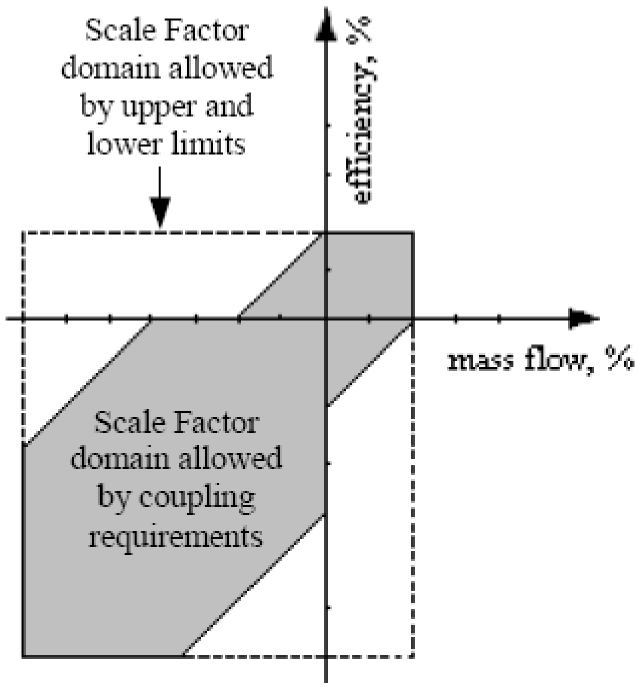

Figure 8: Scale Factor domains between efficiency and mass-flow for compressor degradation.

10.0 FLIGHT LINE TROUBLESHOOTING USING EXPERT SYSTEMS

In the late 1980's, a joint RAAF, Pratt and Whitney and DSTO team was set up to develop a concept demonstrator for the use of expert systems in troubleshooting TF30 engine faults at the flight line. The concept demonstrator was called the Interactive Fault Diagnosis and Isolation System (IFDIS). The original requirement for IFDIS was the need to improve the on-wing troubleshooting of TF30 engine faults so as to reduce the excessive number of unnecessary engine removals arising from incorrect fault diagnosis. A demonstrator version was successfully developed and trialed in 1989 [20,21]. Implementation of the system did not proceed at that time, but renewed interest in the concept led more recently to a requirement to redevelop IFDIS with the aim of maximising its long-term supportability across a number of modern computer platforms and over several cycles of system upgrades. This aim was met by redesigning IFDIS [22] as an advanced web-based expert system that used standard commercially available software packages to implement most of its functions, such as the database engine, the active web server and the web browser. As a result, the specific software code (mainly in the active server pages and the inference engine) and the database of TF30 engine specific information (the data and the rules) make up less that one percent of the total system.

IFDIS performs the role of an intelligent assistant and so it was designed to help troubleshooting in an interactive fashion. Two essential features of troubleshooting a gas turbine are implicit to the design. These are: the ability to separate the problem domain into a finite number of discrete recognisable problems; and the ability to assign causal relationships as cascading fault trees. These features are implemented in the structure of the database and so inherent in it. Any other problem domain that showed these same features could use IFDIS with only a change to the information in the database. This would include a wide range of mechanical, pneumatic, hydraulic and electric/electrical systems.

The design of the new IFDIS inference engine and database was based on the troubleshooting expert system developed by Competitive Advantage Technology Pty Ltd called Diatron. Some significant changes were made to improve overall performance and supportability. The Diatron inference engine was recoded in eXtensible Markup Language (XML) to facilitate machine independent operation. For ease of verification, IFDIS was structured as a set of separate problems each with its own independent set of rules. This facilitated the use of the simplest type of expert system in the re-design, and improved the diagnostic response times, but came at the expense of a more complicated database. Importantly, for the gas turbine diagnostic problem, the inference engine was structured to handle multiple levels of nested rules by assigning a value to a symptom in the conclusion of one rule that is a condition of another rule.

An important feature of the inference engine is non-monotonic reasoning, this allows the user to engage in " what if " scenarios by stepping back and forth through the diagnostic session, changing the symptoms and re-assessing the answers as required. This feature is useful both in engine troubleshooting and in learning the troubleshooting process. The "undoing" process can continue back to the first question of the session. Naturally, changing an answer can lead to different questions being asked subsequently in the session since the diagnosis has moved to a different point in the answer-space. This reflects the fact that the diagnostic problem is structured as a multiple fault tree with many branches. In the inference engine, the symptoms for a selected problem are ranked in order and this controls the order the rules are passed to the inference engine. In responding to the interactive session, the user may supply "Don't Know" answers to the symptoms, resulting in "Known" or "Not Known" symptom states as well as "Not Answered", "Answered", or "Changed" symptom states. The rule and condition states can be "True", "False" or "Not Determined" and the resultant fault status can be "Indicated", "Possible", or "Not Indicated".

An important feature of the database is that it contains all the knowledge and causal relations acquired for the particular problem set. Consequently, the engine maintenance authority only needs to maintain the database to add additional problems or modify engine specific information due to some configuration change. The database comprises of a set of rules added in a particular problem order. The rules themselves are simply entries in a list of Categories, Problems, Faults, Rules, Actions, Reasons, Symptom Choices and Symptoms. These lists simplify the database structure but it means all conditions are joined by "AND" rather than allowing "OR" connections. To reduce database access during operation and to speed up response in a served network, a generic program is used to automatically convert the database information into the XML code lists required by the inference engine.

Currently, IFDIS covers 18 observable faults (or symptoms) with an emphasis on After-Burner operational problems. IFDIS and GPA diagnostics share some common symptoms, like high Turbine Inlet Temperature, but they diagnose different causes. For example, GPA would look at causes such as: reduced High Pressure Compressor mass flow, decreased Low Pressure Compressor efficiency, or eroded turbine Nozzle Guide Vanes. Whereas, IFDIS would look at causes such as: a faulty Engine Gas Temperature probe, un-trimmed fuel control, mis-scheduled Mach number actuator or a broken cockpit gauge. In diagnosing these 18 faults, IFDIS looks at 113 possible causes and uses 326 rules to do so. These faults, causes and rules are based on the TF30 troubleshooting manuals as well as RAAF and Pratt and Whitney operational experience, and they have been verified by the original IFDIS development team. Overall, IFDIS covers 30% of the possible faults, some 70% of the faults seen and 90% of the faults diagnosable on-wing.

The 1999 version of IFDIS has been on operational trial at RAAF Amberley since November 1999. Installed on a notebook PC it has been rotated through the two flight lines and the two test-cells. As a result of its successful operation, a production version of IFDIS is being developed for deployment in early 2002.

11.0 CONCLUSION

A number of advanced diagnostic tools have been developed to support the RAAF in maintaining the TF30 engines in the F-111 through to the Life of Type. These involve: a modern engine acceptance test system for the TF30 test-cells, a suite of advanced gas path analysis methods for diagnosing faults to a modular level using test-cell data, and an expert system for troubleshooting engine faults at the flight line.

The retro-fitting of such modern engine health management systems to old engines poses a number of difficulties, in terms of lack of instrumentation, information and policy, that can lead to trade-offs that blunt their effectiveness. In the process of developing a practical and robust diagnostic system for the TF30 engine there have been a number of lessons learned. Firstly, no one single technology or methodology can provide all the answers. Each technique detects different faults, and even the three gas path methods presented here have different levels of fault coverage. Secondly, a robust gas path diagnostic system requires the simultaneous use of a number of complementary methods, so as to play to the strengths and overcome the weaknesses of the individual methods. For example, in this paper, both the Performance Stack and the Adaptive Model diagnose the exhaust nozzle fault and so add credibility to this diagnosis. Finally, the successful development of gas turbine diagnostics requires the early and active participation of the end-user in their development and evaluation. In particular, the end-user must be prepared to trial baseline versions of these techniques so they can be evolved over time.

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Appendix: Specific Indicators of TF30 Maintenance

A1.0 COSTS

RAAF initially operated three TF30 Variants: P-1-3, 107, 109. The maintenance facility at RAAF Base Amberley is the only RAAF Gas Turbine deeper Maintenance facility.

Bay Service Costs

Hot end component Inspection/Replacement at 750-800 ENHRS Operation

Man-hours – 300@ $65/ hr	=$20K
Spares – hot end components	=$150K
Test – man-hours + fuel	=$10K
Total cost – average	=$180K

Overhaul Costs

Overhaul. A complete strip, rebuild and test of the engine at 1500 ENHRS

Man-hours – 2500@ $65/hr	=$160K
Spares – average	=$250K
Test – man-hours + fuel cost	=$20K
Total cost – average	=$430K

Major Repair Costs

Any maintenance requiring access to a compressor and hence, vertical strip

Man-hours – 1800@$65/hr	=$120K
Spares – average	=$100K
Test – average	=$12K
Total Cost – average	=$235K

Rectification Costs

Man-hours – 120@$65/hr	=$8K
Spares – average	=$50K

Test – 2x $3L runs =$6K

Total cost – average =$64K

A2.0 TF30 ENGINE CONDITION MONITORING (CMM)

Reliability, Availability, and Maintainability (RAM) Team

Team Leader is a an APS PO2

Condition Monitoring Techniques

Spectrometric Oil Analysis Program (SOAP)

Wear Debris Analysis (WDA)

Remote Visual Inspection (RVI)

Vibration Analysis (VIB)

Performance analysis (PERF)

Definitions

Detection – identification of symptoms using one or more techniques

Diagnosis – identification of the failure mode, severity and location

Prognosis – prediction of remaining life under service conditions

A3.0 COST OF OWNERSHIP TRENDS

1990 $3.5K/ENHR

1992 $3.2K/ENHR

1995 $2.2K/ENHR

A4.0 RELEVANT DSTO CONTRIBUTIONS

DSTO has developed advanced vibration, gas-path and oil condition diagnostic techniques which in part are responsible for a decrease in the cost of engine maintenance, and an improvement in engine reliability.

DSTO has provided airworthiness advice on cracks and metallurgical flaws found in critical rotating engine components. Particular examples are the fan disc balance weight cracking and fan disc tie bolthole cracking. DSTO-AVD advice was crucial in lifting the suspension of flying operations on the fleet. DSTO has also been involved in analysis of F-111 usage for verifying the lives of safety-critical components.

A5.0 RAAF STRATEGIC TF30 OBJECTIVES

1) To support the TF30 in-country until year 2020. This requires:
    a) A source of engine spares until year 2020, and
    b) A source of technical information until year 2020.
2) There are two general activity directions to support the TF30 until year 2020. These are:
    a) Improve TF30 reliability, availability and maintainability, and hence reduce the costs of ownership.
    b) Maintain an in-country deep level TF30 maintenance facility.

A6.0 RAAF TF30 OBJECTIVES (ACHIEVABLE GOALS AND TARGET DATE IDENTIFIED)

Objective 1

To extend the bay service interval[1] of the TF30 engine by 250 hours, and hence increase TF30 availability and reduce the cost of ownership of the TF30 engine. Required date for completion: Year 2000. Activities required:

1) Activity 1. Analyse TF30 maintenance records to determine those engine components or systems that limit the bay-service interval of the engine hot-end. This activity will provide a focus for efforts aimed at extending the bay-service life of the TF30 {RAAF/DSTO}.
2) Activity 2. Improve the performance of the TF30 combustion system. Activity 2 must be co-ordinated with combustor life extension activities being performed in USA. A co-operative joint program is recommended, administered through the TF30 CIP. This activity should be completed by Jun 97 if the RAAF is to realise economical benefits. Combustion system activity shall be performed with the following phases:
    a) Phase 1. Develop modifications for the combustor liner to improve combustion zone flow field characteristics {DSTO}.
    b) Phase 2. Develop thermal barrier coating systems to improve combustor liner durability {DSTO}.
    c) Phase 3. Develop a TF30 combustion system rig to validate proposed modifications {DSTO}.
    d) Phase 4. Perform a finite element structural analysis of the combustor liner {DSTO}.
    e) Phase 5. Develop instrumentation for the TF30 combustion system rig {DSTO}.

[1]Current TF30 bay service life is 800 -50 hours.

COMBUSTOR SYSTEM PHASE	DSTO TASK NUMBER	COMMENTS	COMPLETION DATE
1	94-097		Jun 97
2	94-097	Investigation of coating application to engine environment (rig and engine test).	Jun 97
	94-112	Materials division to investigate coating material properties aspects.	Jan 96
3	94-097	Rig required to perform phases 1 and 2.	Jun 95
4	94-110	Required to support phase 1 activities.	Jun 95
5	94-110	Heat flux and radiation sensors to be developed.	Jun 95

Objective 2

To develop an on-condition style maintenance philosophy for the TF30 engine to replace the existing core engine maintenance philosophy. Required date for completion: Year 2005. Activities required - the following activities shall be performed to achieve objective 2:

1) Activity 1. Analyse the existing core maintenance philosophy applied to RAAF TF30 engines, and devise an alternative on-condition/modular maintenance philosophy. Determine those key actions required to replace the existing core maintenance philosophy.

2) Activity 2. Develop a vibration analysis capability able to diagnose the onset of faults within the TF30 mechanical systems. The vibration analysis activity shall be performed with these phases:
    a) {DSTO}
    b) {DSTO}
    c) {DSTO}

3) Activity 3. Develop an engine performance analysis tool able to diagnose faults within the major gas path components of the TF30. The engine performance activity shall be performed with these phases:
    a) {DSTO}
    b) {DSTO}
    c) {DSTO}

Objective 3

To develop techniques that allow the detection of mainline engine bearing incipient failures, and the identification of the faulty bearing, without requiring engine disassembly. Required date for completion: Year 2000.

Objective 4

To develop a means of assuring the quality of new or refurbished mainline engine bearings before fitment, and provide pass/fail criteria for these bearings. Required date for completion: Year 1996.

Objective 5

To provide techniques for visual inspection of internal gas path components installed in the engine (e.g. compressor stators, nozzle guide vanes), without requiring major disassembly. Required date for completion: Year 2000.

Objective 6

To increase the durability of TF30 inlet guide vanes, which have proven susceptible to cracking. Required date for completion: Year 2000.

A7.0 THE CHANGING MAINTENANCE ENVIRONMENT

Over recent years there has been a significant growth in the extent of engineering services contracted to industry by the ADF to support the through-life structural and mechanical integrity management of ADF aircraft.

The amount of engineering work being contracted by the ADF to AeroStructures Australia is growing. Some of this work would, in the past, have been performed by AVD and would have helped senior staff acquire the expertise necessary to provide the reliable advice that the ADF requires of AVD. With the changing work patterns, junior AVD staff may experience difficulty in building up this expertise.

All new aircraft will have provision for the contracting of Integrated Logistics Support (ILS) to industry. ILS items of special significance to AVD are fleet management and aircraft maintenance. The ADF elements most affected by these ILS items are the Logistics Management Squadrons, which are scheduled for considerable down-sizing.

It is expected that ILS would, normally, be provided by the OEM. ILS is a high-cost item that would typically equate, over the life-cycle of the aircraft, to between one and two times the aircraft purchase cost.

It appears that ILS is an Australian-unique initiative. Other military operators have not introduced it, so the ADF is embarking on a “do it alone” scenario with the associated risk of an unfavourable outcome. ILS ushers in a new paradigm for both the contract manager (the ADF) and the contractor (the OEM).

In the case of the Lead-in Fighter (LIF), tasks such as airframe fatigue testing, collection of usage profiles, and working out the LOT for RAAF operations, have been passed to BAe under the ILS contract. The large extent of the through-life support contracted to the OEM for the LIF has been of concern to technical airworthiness managers in the RAAF and to senior staff at AMRL. Because the LIF is a training aircraft, the potential existed to apply ILS more widely than in the case of operational aircraft.

Aircraft maintenance initiatives within ILS are likely to affect AVD work on repairable (or replaceable) items such as engines and helicopter dynamic components.

Because Health and Usage Monitoring Systems (HUMS) have a major impact on aircraft maintenance and fleet management, their role within the ILS contract environment needs to be examined.

AVD has the opportunity to be pro-active in helping to define ILS requirements as part of the tendering process. Vigilance at the "Request For Tender" stage may reduce the likelihood of "nasties" (such as those that "slipped through" for the LIF) being incorporated in an ILS contract.

The proposed contracting out of much of 501 Wing's TF30 engine maintenance work (for the F-111C) is a current "experiment" that follows a similar pattern to that proposed under ILS contracts. Over the years numerous AVD staff have improved their knowledge-base through attachments to 501 Wing; that is likely to become less viable as the work is contracted out.

Provision of advice by AVD to the contract manager (the ADF) and to the contractor (presumably for a fee) would raise the "conflict of interest" issue.

All changes present both threats and opportunities. The implementation of ILS is no different. It is up to AVD to blunt the threats and grab the opportunities.

A8.0 CONCLUSIONS

Obviously in any aging platform, there is increasing potential for unanticipated problems which will require rectification, and such occurrences could influence cost and availability. In addition, there are systems other than the airframe and engines that are highly relevant in F-111 PWD considerations (avionics, flight controls, etc). Some of those systems may lead to increasing maintenance costs and availability problems after 2010 unless a proactive strategy is adopted for them, similar to what has been done for the airframe and engine. DSTO (AOD) has had some input on aging avionics systems.